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PARKING PRIVATE CARS AND SPATIAL ACCESSIBILITY IN HELSINKI CAPITAL REGION – Parking time as a part of the total travel time

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Tiivistelmä/Referat – Abstract

Accessibility – what can be reached from a given point in space and how – is an essential field of study to measure the physical structure of cities, travel mode choices of residents, and the competitiveness of areas. Researchers increasingly acknowledge that accessibility is a fundamental concept on understanding how urban regions work and its position in future development of cities is paramount. Travel time is considered an intuitive measure to indicate accessibility and a strong predictor of mode choice, and usually, private car is the fastest mode of transport in urban environments.

A central issue which stems from private cars and accessibility is the process of *searching for parking*. An understudied issue, the rather stressful activity is engaged in when arriving by car at the general area of desired parking, but no space is available. Motorists are then forced to continue search for parking, significantly contributing to urban congestion. In catering to mobility rather than accessibility, the modern urban planning has made it challenging to move away from private cars toward alternative, often more sustainable, modes of transport. Travel time studies, and more specifically, parking studies, can produce accurate data to aid in this transformation.

In this thesis, a parking related research survey was developed and conducted in the Helsinki Capital Region, Finland. Adhering to the *door-to-door approach*, the survey respondents were enquired how long it took for them to find a parking place and park their car, and walk from the car to the destination in different postal code areas of Helsinki Capital Region. To explain a hypothetical variation in *parking process* durations (searching for parking, and walking to one's destination) in different areas, additional questions, such as the time of the day of parking, were presented. The invitation to respond to the survey was mostly spread on the social media platform Facebook. The survey, filled out with a web application specifically programmed for this thesis, received 5200 data rows from over 1000 unique visitors.

The survey results indicate that there are spatial differences in parking process durations in different postal code areas of the Helsinki Capital Region. The inner city of Helsinki was experienced as the most difficult location to park in with regional subcenters such as Matinkylä, Espoo and Tikkurila, Vantaa, receiving relatively long parking process durations. Short parking process durations were reported from scarcely built areas but more often than not these areas had extreme values reported. Interestingly, area familiarity did not necessarily translate to faster parking process, while the type of the usual parking place was a better indicator. Out of the spatial explanatory variables added in the survey data processing, zones of urban structure (yhdyskuntarakenteen vyöhykkeet) could be used to find statistically significant differences in the parking process between variable groups and study area municipalities.

Making use of the Helsinki Region Travel Time Matrix, a dataset developed by the research group Digital Geography Lab of the University of Helsinki, the thesis survey data was compared to total travel chain durations. The thesis survey data indicates that the proportion of time it takes to park one's car and walk to one's destination is a much larger part of the entire travel chain than previously estimated in the dataset. The parking process times are proportionally largest in the inner city of Helsinki, where the reported parking process duration exceeds that of the actual driving segment.

This thesis, its entire version history, and all of the scripts developed for it have been made available at GitHub (https://github.com/sampoves/thesis-data-analysis).

Avainsanat – Nyckelord – Keywords
accessibility, door-to-door approach, GIS, Helsinki Capital Region, open data, parking search, parking survey, PPGIS, private car, travel time

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Tiivistelmä/Referat – Abstract

Saavutettavuus – mitä tietystä paikasta voidaan saavuttaa ja miten – on keskeinen käsite, kun tutkitaan kaupunkirakennetta, asukkaiden liikkumistapavalintoja sekä alueiden keskinäistä kilpailukykyä. Tutkijat ovat entistä enemmän yhtä mieltä siitä, että kaupunkien tulevaisuudentutkimuksessa tulee ottaa huomioon saavutettavuus. Matka-aikaa pidetään intuitiivisena tapana mitata saavutettavuutta ja muuttujana se ennustaa vahvasti liikkumistapavalintaa. Kaupunkiympäristöissä henkilöauto on usein nopein kulkumuoto.

Pysäköintipaikan etsiminen on kaupunkien autoilijoille tuttu prosessi, jossa yhdistyy henkilöautojen ja saavutettavuuden yhteensovittamisen haastavuus. Autoilija päätyy pysäköintipaikan etsintään silloin, kun autolle ei ole saatavilla pysäköintipaikkaa sillä alueella, jonne olisi tahdottu pysäköidä. Autoilija joutuu kiertämään aluetta niin kauan, kuin pysäköintipaikka vapautuu. Tällainen liikenne on omiaan pahentamaan kaupunkien ruuhkia. Perinteisesti kaupunkisuunnittelua on toteutettu mobiliteetin (mitä voidaan saavuttaa tietyssä aikamääreessä) ehdoilla, kiinnittäen vähemmän huomiota saavutettavuuteen. Vuosikymmenten mobiliteettipainotetun kaupunkisuunnittelun jälkeen on haasteellista kehittää kaupunkia, jossa henkilöautoliikenteen osuus on pienempi. Henkilöautoliikenteen kasvun rajoittaminen vaihtoehtoisilla liikumistavoilla on kaupunkialueiden edun mukaista. Matka-aikatutkimukset ja tarkemmin, pysäköintiaikatutkimukset, ovat eräs keino edelläkuvatun muutoksen edesauttamiseksi.

Tässä pro gradu -tutkielmassa kehitettiin ja toteutettiin henkilöautojen pysäköintiä koskeva kyselytutkimus. Pääkaupunkiseudulle sijoittuneessa tutkimuksessa kysyttiin, kuinka kauan vastaajalla yleensä kestää pysäköidä autonsa ja kävellä autolta matkan lopulliseen määränpäähän seudun eri postinumeroalueilla (*pysäköintiprosessi*). Jotta hypoteettinen pysäköintiprosessissa tapahtuva ajallinen vaihtelu voitaisiin selittää tutkimuksen analyysivaiheessa, kyselyssä esitettiin joitain lisäkysymyksiä, esimerkiksi minä vuorokaudenaikana vastaaja yleensä pysäköi alueelle. Kyselyä mainostettiin valtaosin sosiaalisessa mediassa, Facebookin kaupunginosaryhmissä. Kysely täytettiin tätä tutkimusta varten ohjelmoidussa verkkosovelluksessa. Kyselystä saatiin yli 5200 vastausta yli tuhannelta tutkimukseen osallistuneelta henkilöltä.

Kyselyn tutkimustulokset viittaavat siihen, että pysäköintiajoissa sekä kävelyajoissa autolta määränpäähän on eroavaisuuksia pääkaupunkiseudun postinumeroalueiden välillä. Pisimmät pysäköintiprosessit mitattiin Helsingin kantakaupungissa. Alueellisesti merkittävän pitkiä pysäköintiprosesseja löytyi muun muassa Matinkylästä Espoosta sekä Vantaan Tikkurilasta. Lyhyitä pysäköinti- ja kävelyaikoja mitattiin enimmäkseen pääkaupunkiseudun harvasti asutuilla postinumeroalueilla, mutta myös näillä alueilla esiintyi merkittäviä eroavaisuuksia pysäköintiaikojen pituuksissa. Huomionarvoista tuloksissa oli, että lähialuetuntemus ei nopeuttanut pysäköintitapahtumaa. Sen sijaan pysäköintipaikan tyyppi oli parempi indikaattori, tuottaen pisimmät pysäköintiprosessit kadunvarsipysäköinnissä ja lyhyimmät pysäköintihalleissa. Kyselyaineistoon lisättiin prosessointivaiheessa kaksi spatiaalista selittävää muuttujaa, keinotekoisen maanpeitteen prosenttiosuus sekä vallalla oleva yhdyskuntarakenteen vyöhyke. Yhdyskuntarakenteen vyöhyke tuotti tilastollisesti merkitseviä eroja tutkimusalueen kaupunkien sekä vyöhykkeiden välille.

Tässä tutkimuksessa hyödynnettiin Helsingin yliopiston Digital Geography Labin tuottamaa Helsingin alueen matka-aikamatriisia, josta laskettiin kokonaismatka-ajat postinumeroalueiden välille. Kyselyaineisto ja matka-aikamatriisi yhdistettiin pysäköintiprosessin osuuden selvittämiseksi kokonaismatka-ajasta. Tästä saatiin selville, että matka-aikamatriisin arvio pysäköintiprosessin pituudesta oli huomattavasti alhaisempi verrattuna pysäköintikyselyssä tuotettuun aineistoon. Pysäköintiprosessi oli koko matkaan suhteutettuna pisin Helsingin kantakaupungissa, missä pysäköintipaikan löytämiseen, pysäköintiin ja määränpäähän kulunut aika oli monin paikoin pidempi kuin matka-aikamatriisista laskettu kokonaismatka-aika.

Tämä pro gradu -tutkielma, sen koko versiohistoria ja sitä varten tehdyt skriptit ovat julkaistu GitHubissa (https://github.com/sampoves/thesis-data-analysis).

Avainsanat – Nyckelord – Keywords
avoin data, GIS, henkilöauto, matka-aika, ovelta-ovelle-menetelmä, PPGIS, pysäköintikysely, pysäköintipaikan etsiminen, pääkaupunkiseutu, saavutettavuus

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ANOVA	Analysis of Variance test
GIS	Geographic Information System
IDE	Integrated Development Environment
PPGIS	Public Participation Geographic Information System

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1 Introduction

Accessibility – what can be reached from a given point in space and how – is an essential field of study to measure the physical structure of cities, travel mode choices of residents, and the competitiveness of areas (Bertolini et al. 2005; Toivonen et al. 2014). Researchers increasingly acknowledge that accessibility concepts are fundamental on understanding how cities and urban regions work, and the relation of accessibility and land use planning has been linked with sustainable development (te Brömmelstroet et al. 2014; Wegener and Fürst 1999).

Travel time is considered an intuitive measure to indicate accessibility and a strong predictor of mode choice (Frank et al. 2008). In this sense, the private car is usually the fastest mode of transport in an urban environment, surpassing public transport and non-motorised transport (Salonen et al. 2014). The combined effect of the increased use of private car in the last century and the way private cars have molded cities in their current form, personal vehicle traffic accessibility study is at the forefront when attempting to find a way to the sustainable future of urban life.

An issue which rises with private cars and accessibility is the parking. A peculiar feat of private cars is that they are mostly studied when they are in use, which is a vast minority of the time (Diallo et al. 2015). Although almost all private car trips contain two parking events and cars spend 80 % of the time parked, mobility research has traditionally been concentrated on other mobility and transport linked themes, such as congestion and emissions (Bates and Leibling 2012).

In the Helsinki Capital Region, accessibility has been explored in a multitude of studies (Järvi et al. 2014; Toivonen et al. 2014; Laatikainen et al. 2015; Salonen et al. 2016; Tenkanen 2017; Tenkanen et al. 2018). Many of these works employ a recent dataset released by the research group Digital Geography Lab, based in the University of Helsinki, the Helsinki Region Travel Time Matrix (Tenkanen et al. 2018). Using a spatial grid of square cells laid over the Helsinki Capital Region, this dataset contains travel time data from every cell to all the others by walking, bicycling, public transport, and private car. In Helsinki Region Travel Time Matrix, public transport and private car journeys employ the door-to-door approach, as introduced by Salonen and Toivonen (2013). The approach strives for added realism in modelling accessibility. For example, to realistically model travel times by private car, one needs to take into account the whole process of the journey, or the *travel chain*, including walking from the point of origin to the location of one's car, then driving the car to a location near the destination, finding a parking place, and, in the end, walking from one's car to the final destination.

This thesis builds upon the work of Digital Geography Lab (https://www.helsinki.fi/en/researchgroups/digital-geography-lab) of the University of Helsinki. Adapting the same study area as Helsinki Region Travel Time Matrix uses, the study aims to find out the spatial variation in durations that it takes to park one's private car in the Helsinki Capital Region and how long it took to walk from one's car to the final destination of a journey. In the current iteration of Helsinki Region

Travel Time Matrix, the parking process – searching for parking, parking one's car, and walking to the destination – is represented as the same static value for all areas of the Helsinki Capital Region based on previous literature (Tenkanen and Toivonen 2020; Kalenoja and Häyrynen 2003).

However, this thesis makes the hypothesis that the variation in times that it takes to find a parking place and walk from one's car to the destination varies greatly inside the Helsinki Capital Region and that the proportion of the parking process is a large share of the total travel time, especially in the densely populated areas. The data for the thesis was gathered via a survey using a web survey application specifically developed for this purpose.

As preparation for this thesis, I searched for similar parking studies, but could not find any. According to Diallo et al. (2015), parking studies are infrequent because of the cost or difficulty to collect applicable data and the scope needed. As such, this thesis is breaking new ground at least in Finland, if not everywhere else.

This thesis promotes research transparency and repeatability. All parts of this thesis are available online at GitHub (https://github.com/sampoves/Masters-2020 and https://github.com/sampoves/thesis-data-analysis). This includes the entire thesis in LaTeX format, the parking survey programmed in JavaScript, instructions to set up the web server as used in this research survey, and the interactive survey data and analysis applications programmed in Python and R. Complete development histories of all components are included. In addition to the work proper, as a side product, a point based variant of the park survey (https://github.com/sampoves/leaflet-map-survey-point) have been made available.

The research questions for this thesis are:

I What are the spatial differences in the time that it takes to find a parking spot and park one's car in the study area?

II If spatial differences are detected, what explains them?

III What is the significance of the parking process to the overall travel time?

In addition to these research questions, this thesis explores how well the map survey created for this thesis worked in collecting user data in a spatial manner.

2 Background

2.1 Private cars as a mode of urban transport

The number of private cars is globally on the rise. According to one estimation, the world reached one billion cars in 2020 (Sperling and Gordon 2009). International Organization of Motor Vehicle Manufacturers (OICA) estimates that there were already at 950 million private cars in 2015 (OICA 2020). As the production of private cars is expected to continue, eyes must turn to managing the vast quantity of personal transportation in cities and in their surroundings. This is a question of mitigation of climate change, but also ensuring the economic performance of cities, and maximising the quality of life for urban citizens (Bertolini and le Clercq 2003).

Since the last century, urban landscapes have experienced change toward car based mobility, where streets have incrementally widened and parking standards continually increased. This space has been mostly taken from all other users of public space to accommodate cars (Cervero et al. 2017). As cars have become a most common sight in cities, the mitigation of their adverse effects have become an important focus in policy. A major challenge cities face today is the relation of mobility of people and the urban land use. It has been shown that parking policy is an effective tool in the management of this challenge (Diallo et al. 2015; Marsden 2006).

One goal of parking policy is an urban environment less dependant on private cars. However, a central issue in attempting to shape urban development in a direction that's less dependent on cars is that the alternatives fail to reach the quality of accessibility provided by private cars (Bertolini and le Clercq 2003). In Willson (2013), the author discusses that parking requirements have taken cities into a chokehold. The requirements are responsible of creating the most wasteful sections of transport and land use complexes, the unoccupied parking spaces. To alleviate this situation, Willson has developed a 12-step toolkit to help planners make more informed decisions on the subject. These steps include points such as accounting for market conditions, and the consideration for alternative modes of transport, such as shuttle services or bicycles. Results of this thesis aim to illustrate the actual parking conditions in Helsinki Capital Region, which could be of use to planners willing to take on Willson's toolkit.

2.2 Spatial accessibility

Considering transportation of people in cities, It may be thought that it is of highest priority to reach places as fast as possible. This is called *spatial mobility*, movement which can be observed. However, people are ultimately not interested in measuring time units, but in social and economic interactions. It can then be said that the actual matter to focus in transporting people in cities is not mobility, but *accessibility*. Accessibility can be defined as potential movement, observed through modelling. In accessibility, it is possible to attain a more realistic view into what is possible with available resources, such as time, and combine this with important issues regarding the sustainable development of cities (Hodge 1997; Tenkanen 2017; Cervero et al. 2017).

First discussed by Hansen (1959), accessibility as a concept has been widely studied in the decades that followed. In these first efforts, Hansen succeeded in showing that locations in Washington D.C., United States, that had good accessibility were more likely to end up developed. These areas would also be developed at a higher density.

Torsten Hägerstrand's classic time geography approach developed further the idea that accessibility is an intricate complex of interdisciplinary tendencies. Individuals can be viewed as a bearers of action spaces of varying sizes and durations, which are determined by their social role, income, and how advanced technology they can access. Individuals are bound to their time budgets which are indivisible from certain constraints: the capacity, coupling, and institutional constraints (Wegener and Fürst 1999; Hägerstrand 1970).

Continuing on Hägerstrand's action-space line of thinking, Zahavi (1974) proposed that individuals are not attempting to minimise travel time or cost required for a number of activities, but to maximise what is available to them considering their travel times and monetary budgets. Zahavi's theory can explain why the expansion of private car use has been as extensive as it has been. According to Wegener and Fürst (1999), the theory sheds light on why the motorisation in the twentieth century caused even longer and more car trips when travel speed gains were attained and why shopping centers in outskirts of cities can attract customers from ever more larger areas of influence. Moreover, indicated by the results of Salonen et al. (2014) and discussed in Jain and Lyons (2008), it may be argued that individuals do not merely choose travel modes on economic terms, elaborating that travel time itself valuable. Individuals' travel time budget is explored in detail in Mokhtarian and Chen (2004).

More recently, Geurs and van Wee (2004) and Bertolini and le Clercq (2003) have provided their definitions for accessibility. Geurs and van Wee argue that accessibility should be associated with land use and transport systems in society and this would provide individuals with opportunities to take part in activities in different locations. According to Bertolini and le Clercq 2003, accessibility refers to the quantity and the diversity of spatial opportunities which can be reached within a certain amount of time.

2.3 Previous parking studies

Parking is an important part of a traffic system as all vehicles need a storage location when they are not in use. Due to increasing amount of cars, cities being built on private car mobility, and parking policy trying to find a balance between raising activity locally and not deterring visitors, motorists have been shown to spend a large percentage of their overall travel chain *searching for parking* (Axhausen and Polak 1991; Marsden 2006; Shoup 2006). A stressful experience for motorists, searching for parking has been identified as an eminent source of urban congestion (Axhausen et al. 1993; Gantelet and

Lefauconnier 2006), and parking policy improvements are much needed for most major cities (Benenson and Martens 2009). According to Young et al. (1991), the quantity and the location of parking affect:

– the congestion on access roads and city streets;
– the efficiency and financial performance of public transport;
– comfort and safety levels of a city and the surroundings, and;
– the form and functioning of the entire area.

As such, parking policy is closely interlocked with potential conflict within different levels of government, city residents, holders of commercial interest, and other special interest groups (Ker and Johnstone 1988). It does not help that parking policy is an urgent matter in most major cities: Arnott (2006) states that on-street parking may be utilised to over 100 % capacity due to double parking, illegal curbside parking, and parking on the sidewalk. One study found that motorists parking in unauthorised space in Paris, France, counts up to 62 % of all parking events (Gantelet and Lefauconnier 2006). Inefficient parking policy also promotes *cruising for parking*, a phenomenon which is partly a symptom of tension between demand and supply, and inefficiently low parking fees on-street (Shoup 2004; 2006). Martens et al. (2010) recognises three types of cruising for parking motorists: the commercial parkers, commuter parkers, and residential parkers.

Parking place problems originate from the mismatch between parking intentions of the motorists and available supply. In some more traditional cases, the mismatch can be addressed with expanding capacity or constrain demand, but in other cases the problem is spatially and temporally specific. For instance, that motorists' knowledge of local parking opportunities may be lacking, or road condition and layout is poor in specific places (Axhausen et al. 1993).

In Teng et al. (2002), off-street parking in New York, United States, was studied through a survey. Specifically pertaining to parking garages, the research quantified that increase in parking information markedly decreased parking search time. In their survey, the parking information most sought after by respondents were the fee structure, hours of operation, and the location on a map. The determinants of parking behaviour is further explored in Spitaels and Maerivoet (2008), where both on-street and off-street parking locations are considered.

Based on the works of Layzell (1985) and Polak and Axhausen (1989), Thompson and Richardson (1998) have defined the *parking process* as a series of decisions by motorists based on updated knowledge gained from experience (figure 1; a definition similar to this is also used by Guo et al. (2013)). The process commences on the start of searching for parking. Parking sites are examined and on the discovery of a favourable car park, a selection is made or the search continues (In Thompson and Richardson (1998) *car park* means both off-street parking garages as well as on-street parking that share common attributes). After leaving a selected car park, the next leg of the parking search process begins. Thompson and Richardson state that motorists must make a choice based on imperfect information, as aspects of the parking process are stochastic and opaque to individuals.

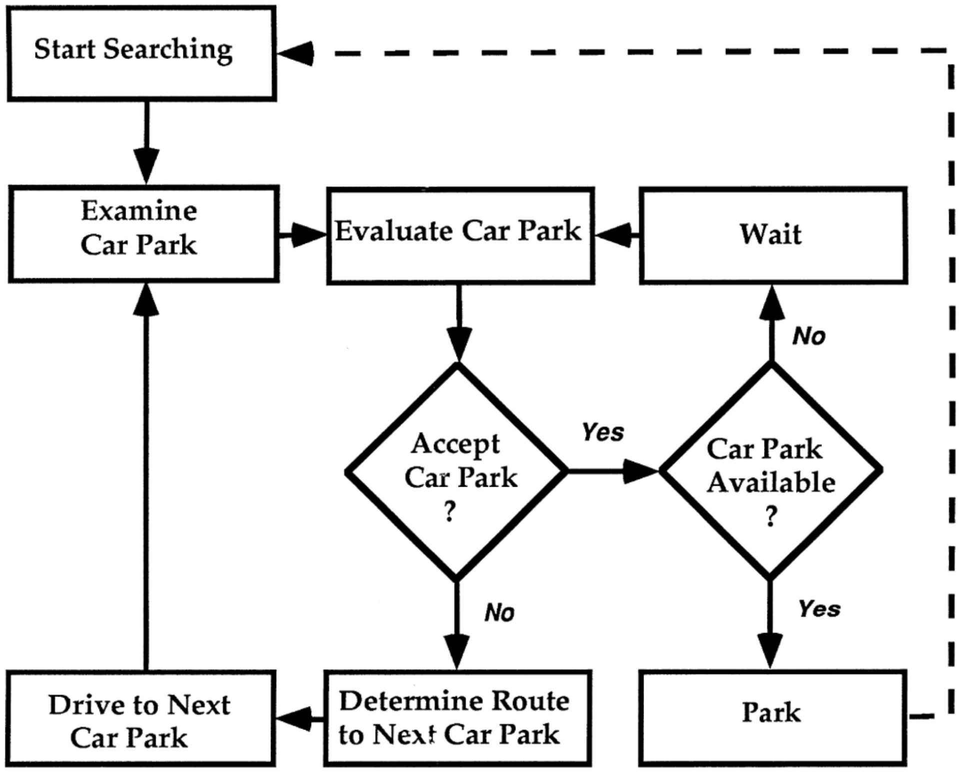


Figure 1. Defined by Layzell (1985) and Polak and Axhausen (1989), parking choice may be considered as a search process in which motorists make linked decisions based on updated knowledge gained from experience. Figure adapted from Thompson and Richardson, 1998, pp. 160.

In Salonen and Toivonen (2013), the accessibility disparity is studied in a comprehensive manner. Many earlier accessibility studies are cast into doubt as they have been simplifying the subject matter, using methods that are not satisfactorily explained, or are simply incompatible. Salonen and Toivonen employ real data in finding compatible methods for calculating travel times for both private car and public transport. Introducing the *door-to-door approach*, the researchers strove for maximum realism when calculating the duration of entire trips, or *travel chains*. In the door-to-door approach for private car, all realistic parts of a journey are taken into account (figure 2). The trip starts at the point of origin (O), from where one walks to where their car is parked at (P). The car drive segment commences and continues until the earliest place where one would like to park at. This is where the parking process starts (see figure 1), and it continues until a parking place is found and the car is parked (P). Finally one walks to the final destination of their journey (D). The door-to-door approach for the private car draws attention to a severely understudied subject, the parking process at the end of every trip made. While they accurately demonstrated the events that take place in realistic private car trips, Salonen and Toivonen themselves touched the subject of parking process only fleetingly. Notably, a parking process comparable to the one included in the door-to-door approach is described and employed in literature as early as in the 1960s (the "park-and-visit" approach, Inwood 1966; May and Turvey 1985; Belloche 2015).

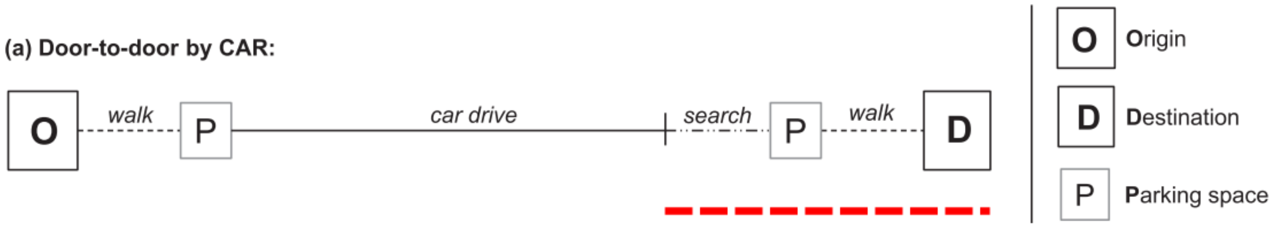


Figure 2. The entire travel chain of a private car using the door-to-door approach. The red dashed line represents the parking process segment of the travel chain. Figure adapted from Salonen and Toivonen (2013).

In this literary review to parking survey, it became apparent that most studies in this field employ a computational model to predict availability or use of parking spaces. Parking survey studies were sparse in number, and according to Diallo et al. (2015), this is because the cost or difficulty to access appropriate data. They also note that complexity and extent of such studies work as a detriment.

In one computational model, van der Goot (1982), based on a parking study in the city of Haarlem, the Netherlands, showed that walking time strongly influenced drivers' choice of parking. An additional finding was that with the parking purpose of "shopping", longer walking times led to longer parking times, and shorter walking times translated to shorter parking times. In addition, in shopping trips, destination choice is influenced by the parking search time (Axhausen et al. 1993). However, it is shown in literature that long term experience in parking search or knowledge of the area does not automatically result in better parking choices or make the parking search shorter (Thompson and Richardson 1998; Teng et al. 2002). Guo et al. (2013) has explored parking search process through an agent-based model in which a supply and demand are incorporated with sequential game-theoretical capacity model to account for motorists' psychological attitudes in university campuses in the United States.

Benenson et al. (2008) propose a parking process model that is spatially explicit and agent-based (termed "PARKAGENT"). This means that the model takes urban elements essential for investigating parking process into account and gives agents instructions on how to react in different circumstances, such as reactions to lack of parking spaces and parking enforcement efforts, to simulate parking behaviour of motorists. This paper shows that the addition of a new parking facility does not much improve average parking search time and walking distance for on-street parking motorists. This was because the new facility, essentially, would change the supply and demand scenario of that area, bringing in motorists to the area who have their journey destinations further away. The paper also states that traditional parking modelling is insufficient in saturated parking situations (most major cities), as it is not possible for these models to consider actions of independent agents who can make decisions on exact Geographic Information System (GIS) data. A detailed view into "PARKAGENT" is described in Martens et al. (2010) alongside with a performance comparison to a non-spatial model of parking. A finding from this paper states that if parking turnover is low for a location (15 % in an hour), the parking occupancy level of 85 %, proposed by Shoup (2004), can be raised up to 95 %. Parking occupancy level can be adjusted with changes to parking fees. The study also finds that if parking turnover reaches 50 % for an hour, the aforementioned optimisation does not work.

Furthermore, Levy and Benenson (2015) propose the model termed "PARKFIT", an GIS algorithm for estimating parking patterns without the need for in-situ behavioural data, and a continuation for the research carried out on "PARKAGENT". If high-resolution infrastructure GIS layers are available, the algorithm can be used to produce estimations – map views – about average distances between private cars aiming for a specific destination and the actual destination parked at, and finally the proportion of cars that fail to find a parking place. The model, however, does not include parking search time.

In a commendably open, data-driven study, Aryandoust et al. (2019) provide methodology and tools for modelling car parking density maps using only travel time measurements. In the study, the freely available Uber travel time data is used to generate maps for 34 cities in multiple countries. Aryandoust et al. manage to reach 90 % accuracy for parking densities and 93 % for circadian rhythm of the traffic in the chosen city of validation, Melbourne, Australia.

Simulation to evaluate parking space availability has also been utilised in, for example, Harris and Dessouky (1997) and Saltzman (1997).

2.4 Parking time estimations

In accessibility studies, the estimations and measurements for parking times are relatively scarce and an understudied subject. In Finland, a parking survey research was conducted for the city of Tampere (Kalenoja and Häyrynen 2003). The authors interviewed individuals that had just finished parking, and enquired after circumstances behind the parking, such as the factors that made them decide on the current parking place and from what direction they drove to the parking place location. In this study, 55 % of interviewees had parked into a parking garage, 33 % on-street and 13 % in other areas. Over 60 % of all interviewees reported that a short walking distance to their destination was of importance. The average time to find a parking place was 0.42 minutes on weekdays (table 1).

Table 1. The average time (minutes) to find a parking place in different types of locations in Tampere, Finland (Kalenoja and Häyrynen 2003).

Parking place type	Weekday	Saturday	Overall
On-street	0.73	2.08	0.80
Other areas	0.16	0.38	0.18
Parking garages	0.22	0.55	0.33
Overall	0.42	0.65	0.46

Internationally, Shoup (2006) has been a landmark paper in private car parking time research. Mustering all research there was available on *cruising for parking*, Shoup was able to display a compilation of results from a wide temporal and spatial pool. The gathered data showed that a range of 8–74 % of a total trip was spent in cruising for parking. The average time to find a curbside parking place was in the range of 3.5–14 minutes. Shoup himself acknowledges the wide variance, saying that in reality some cities may have zero time spent in cruising for parking, while in other locations a large portion of a journey made with private car consists of it. Regarding time spent in searching for parking when travelling by private car, Polak and Axhausen (1990) state that it may constitute up to 25 % of the average total travel time. According to Axhausen and Polak (1991), motorists value short parking search times over the driving time, with parking search time being up to two times more valuable. Parmar et al. (2020) suggest, based on their literature review, that motorists prefer to minimise the "out-vehicle" costs of parking charges, cruising for parking, and walking times, rather than the costs pertaining to the car itself, such as fuel cost and driving time.

In a parking time research carried out in France, it was found out that the average parking search time was especially severe in Paris. In the districts studied in Paris, parking search lasted on average 10 minutes in Commerce district and 7.7 minutes in Saint-Germain district. Extrapolating their results to the entire France, the researchers estimated that 70 million hours, each year, is spent searching for parking places (Gantelet and Lefauconnier 2006). In an other parking time focused paper, on-street parking was modelled and validated with a parking survey. The survey, conducted in Lyon, France, showed especially intolerable parking times in districts near the center of Lyon: an average searching time of 11.1 minutes for Part-Dieu, 9.6 minutes for Charpennes, and 6.3 minutes for Belges. All of these districts provided parking free of charge. In this study, the longest average parking search duration for a district with parking meters was the center of Lyon, Presqu'île, with a result of 6.2 minutes (Belloche 2015).

2.5 Research in participatory GIS and map surveys

In Salonen et al. (2014), Public Participation Geographic Information System (PPGIS) was employed in understanding what is the character of daily mobility in the Helsinki Capital Region and how often the fastest travel mode (in this study, "the most optimal") is selected in these everyday trips. The data received from respondents was compared to routes calculated with advanced multimodal routing models presented in Salonen and Toivonen (2013). The study found that respondents most often chose non-optimal travel modes on "bounded trips" (work, school, or day care) and that instead of the private car, many of the respondents are ready to choose a slower, and less carbon emission intensive means of travel.

Laatikainen et al. (2015) made use of PPGIS in the context of accessibility to urban aquatic environments and the environmental justice perspective that is included in a premise such as this. Employing "SoftGIS" methodology, the researchers were able to gather a large amount of data from users of urban environments through an easy-to-use user interface on the internet (Kyttä and Kahila 2011). The researchers had the opportunity to make use of Finnish Population Register to select a group of potential respondents representative of the study area, the Helsinki Capital Region. In some of the results, researchers point out that even though water is almost omnipresent in the Helsinki Capital Region, the utilisation of PPGIS revealed that proximity of a body of water does not have a clear influence on the real usage, or travel distances and times. This being said, the results showed that in many cases the body of water nearest to an individual was undesirable in some way, prompting the individuals to seek amenities along waterside further away. Also, while some areas of the Helsinki Capital Region are closer to more bodies of water, this fact did not automatically mean good access because of matters such as land ownership issues.

This thesis employs PPGIS in its parking research, approaching the subject matter with a *do-it-yourself* mentality. While Salonen et al. (2014) expected low response rate for their survey research, this thesis aims to demonstrate that extensive scientific data can be feasibly collected in a public participation arrangement with minimal resources, making use of free and open source software in the system design and social media platform communities in the collection of the data.

3 Data and methods

3.1 General workflow

A selection of web applications was designed and programmed for this thesis. In this chapter, the process to create these applications is presented, from the design board to a functional web application to the end stage of data processing and visualisation. Four applications are presented: a spatial web survey for data collection and three separate web applications for the analysis and visualisation of the survey results. These applications directly answer the research questions while providing a possibility for a vast array of additional results and calculations. The general workflow of the thesis data processing, analysis, and visualisation can be viewed in figure 3.

In the thesis research survey web application, a respondent would send data about their parking activities in a specific postal code areas, in a general sense, summing up their experiences in the most recent two years (figure 3, the top two parallelograms). Five questions were posed, and the numerical parking time and walking time questions pertained to the first research question and the following three single-choice questions aimed to answer to the second. The survey was carried out in the four municipalities of the Helsinki Capital Region – Helsinki, Espoo, Vantaa and Kauniainen. The survey gathered 5222 data rows from 1060 unique IP addresses.

After the conclusion of the data collection phase, the survey data was processed, analysed, and visualised using Python and R programming languages. The process started with anonymisation of the IP address data (figure 3, section 1, Anonymise IP addresses), and moved on to the processing proper. In this next step, all input data was processed to better work together. Input data here refer to spatial GIS layers, which were to be used as explanatory variables in the analysis, or visualisation in the various interactive applications developed for the use of this thesis. Some of the spatial layers were streamlined by removing attribute data that was not necessary for this study. Other spatial data, such as the 250 by 250 meter spatial grid of the Helsinki Capital Region, was supplemented with additional data, the postal code area, for the use of the analysis applications in later stages of the workflow (figure 3, section 2, Preprocessing).

In the general workflow section 3, Detect illegal data, the parking survey data was analysed for potentially problematic data. For example, the survey data was analysed for data entries, where the same IP address codes had 1) answered multiple times to same postal code areas, 2) entered identical values to some or all survey questions, and 3) entered anomalously high values in the numeric questions. This section also had the feature to remove any data rows deemed unwanted, but in the end, it was deemed a better solution to remove any problematic data later on in the workflow.

The section 4, insert data into *postal*, prepares the postal code areas data for later analysis. For example, each postal code area was supplemented with data about mean and median parking and walking times in that area, and indicator values of the spatial data were added. For example, in a geoprocessing calculation each postal code area was given a value in percentage how much of its area is artificial according to the CORINE land cover and land use dataset (Finnish Environment Institute 2018). In the thesis general workflow section 5, all of the newly calculated postal code area data was added to the dataframe containing the survey results. This process would help in data analysis and visualisation.

The survey result analysis and visualisation was carried out in R (figure 3, sections 6, 7, and 8). In section 6, Preprocess Travel Time Matrix 2018, the cumbersome dataset was transformed for the specific needs of the analysis applications. Then, in sections 7 and 8, data analysis and visualisation applications were programmed for efficient and flexible data analysis for this thesis, but also to release the survey results to the public, maintaining the mission of openness and transparency of this thesis. The analysis application contains a range of tools for viewing the important properties of the survey data, such as descriptive statistics, different kinds of charts, such as histograms and boxplots and, finally, an interactive map to view the results in a spatial manner. A visitors application helps track the timeline of data collection, cumulatively showing the data rows as they were received. Finally, the travel time comparison application made it possible to analyse the parking process proportion in the total duration of travel chains in the study area. This application was designed to answer in the third research question.

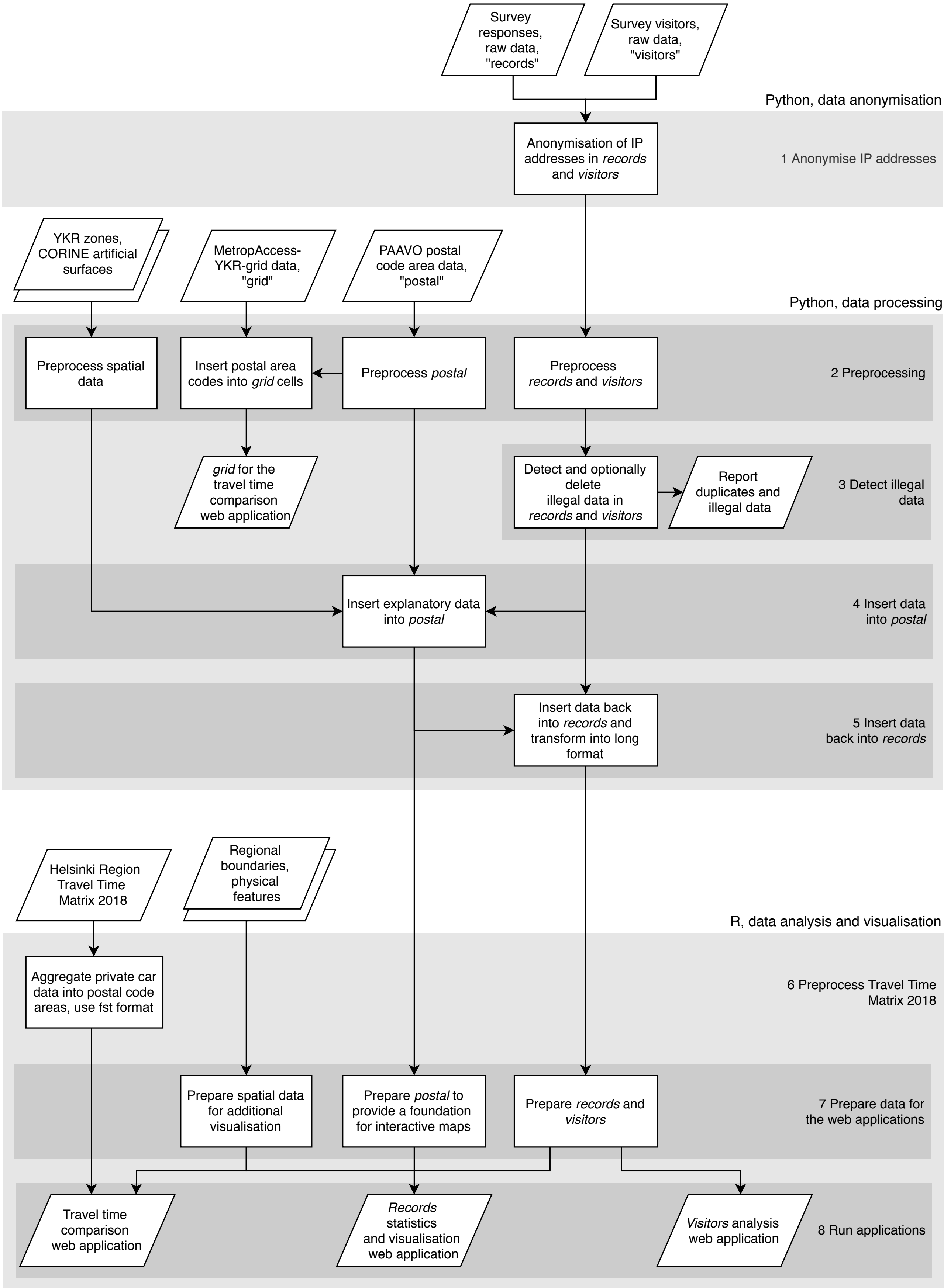


Figure 3. The general workflow of the thesis survey data processing in Python and R.

3.2 Study area

The study area of this thesis is the Helsinki Capital Region in Finland (figure 4). It comprises of the municipalities of Helsinki, Espoo, Vantaa, and Kauniainen and in August 2020 the area had a total population of 1.2 million (Statistics Finland 2020c). In practice, the whole area amalgamates as one complete functional area with boundaries of the municipalities indistinguishable at the street level. Of these four municipalities Helsinki is the hub, and can be considered to contain the only inner city features of the municipalities (Finnish Environment Institute 2013). The urban fabric of Espoo, Vantaa, and Kauniainen mostly consist of suburban areas with an occasional industrial area here and there. Relatively recently, large shopping complexes have risen in important traffic junctions around the cities. The exact boundaries of the study area are based on the dataset *PAAVO open data by postal code area* (Statistics Finland 2019).

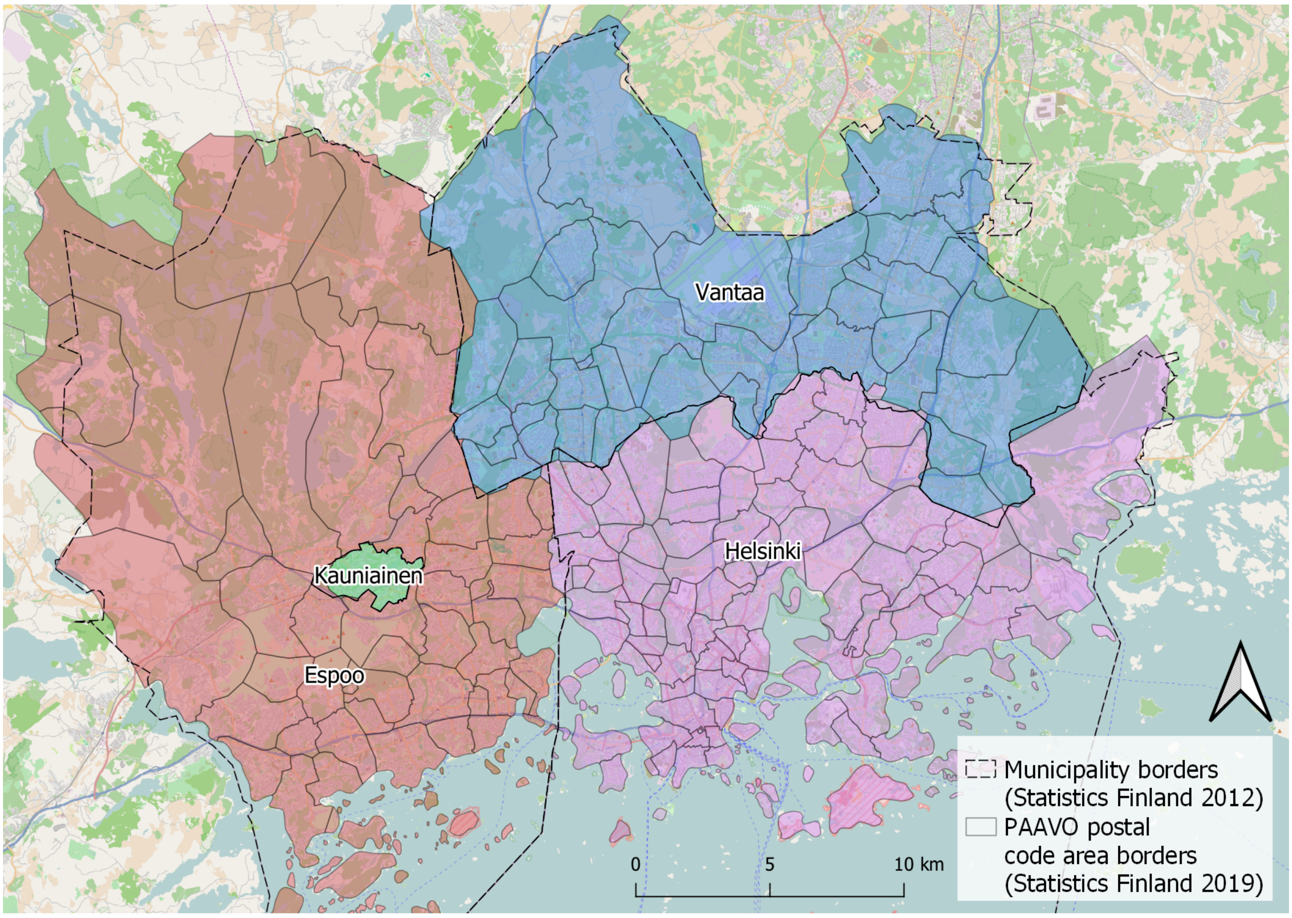


Figure 4. Map of the Helsinki Capital Region, the study area of this thesis. The postal code areas represent the spatial resolution of this thesis. The postal code area boundaries do not completely align with the official municipality boundaries (OpenStreetMap contributors 2020).

The Helsinki Capital Region has experienced considerable growth in the recent past and this trend is poised to continue. According to Statistics Finland (2020b), the population of Helsinki has grown with more than 100 000 people in the last twenty years, and will grow with another 100 000 in the next twenty years. Since 2000, nearly 80 000 people moved to Espoo, and in the next twenty years, more than 50 000 people are forecast to move in. Vantaa follows suit, with an increase of about 100 000 people in 2000–2040. Also Kauniainen grows, albeit in much smaller scale than the three larger Helsinki Capital Region municipalities. In the next twenty years about 1 500 people will move into Kauniainen.

About two thirds of the households in the Helsinki Capital Region own at least a single car (64 %) (figure 5). Private cars are the most ubiquitous in Espoo, where 53 % of households own one car and 19 % own two cars. In the entire Helsinki Capital Region, Inner Helsinki households are the most car-free with 61 % of households not in possession of a car (Liikennevirasto 2018).

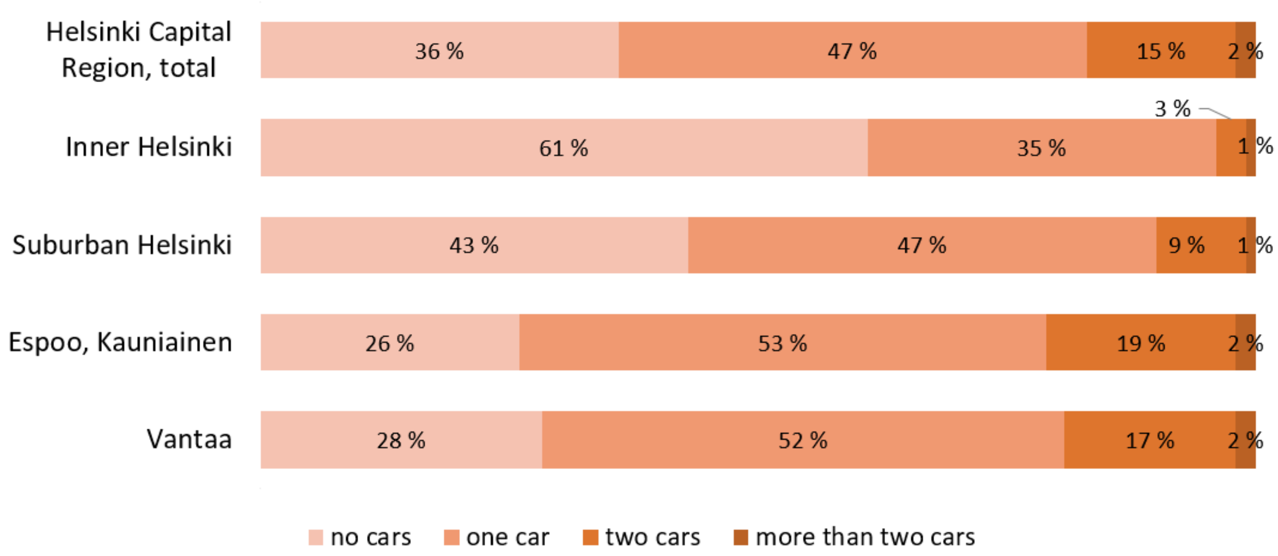


Figure 5. Amount of private cars in households in the Helsinki Capital Region. Adapted from Henkilöliikennetutkimus 2016 (Liikennevirasto 2018).

Even as the share of private car journeys of all travel modes has been on the decrease in recent times in the Helsinki Capital Region, the absolute amount of cars is slightly on the rise in the same area (Brandt et al. 2019; table 2). At the same time, the traffic is increasing in the major roads, such as the beltways Ring I and III (Helsingin seudun liikenne 2020; figure 6). However, the density of private cars (cars / 1000 residents) that are commissioned for traffic is decreasing, perhaps owing the efforts to make public transport more appealing as roads become increasingly congested and parking spaces scarcer (table 3).

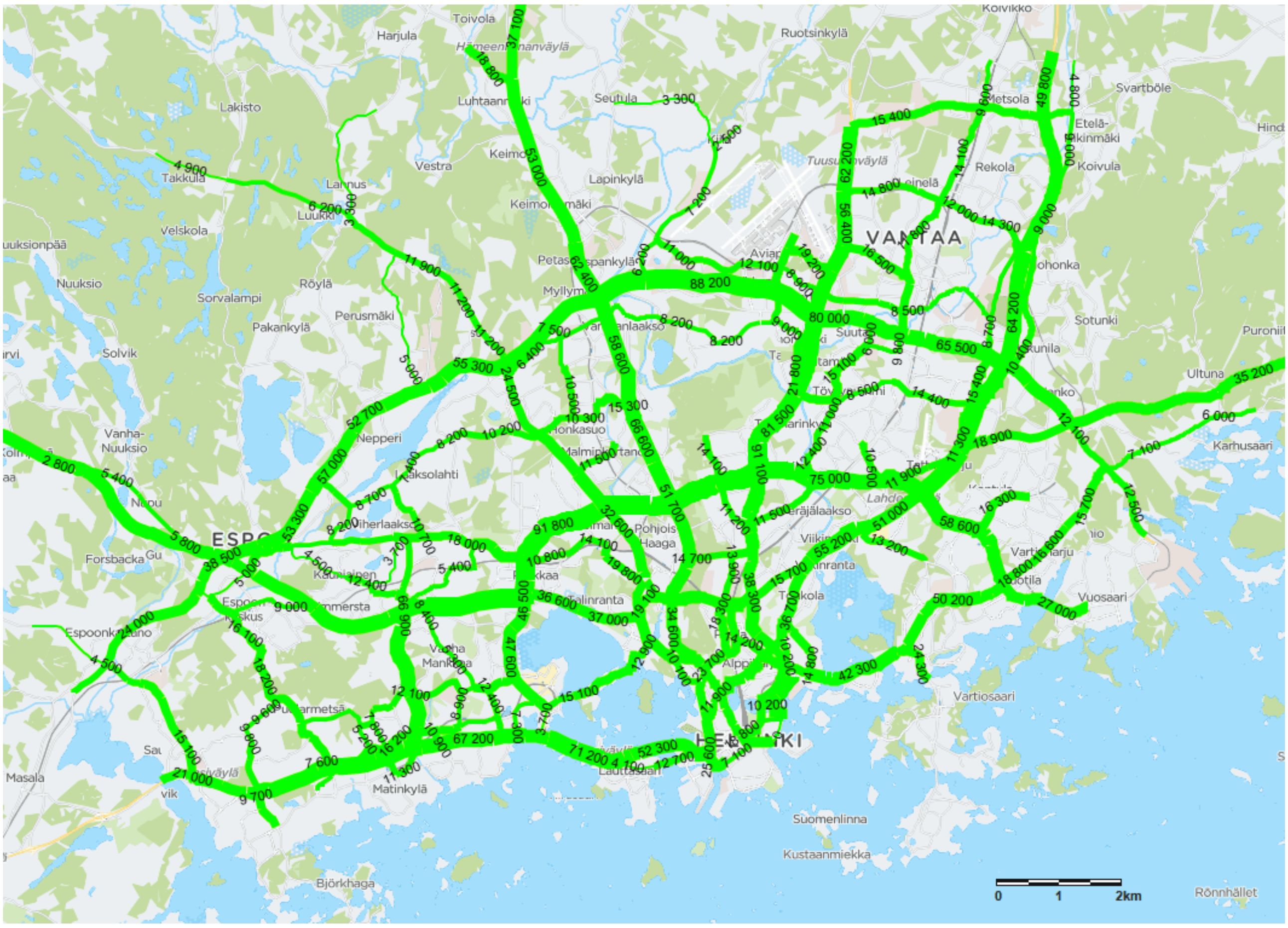


Figure 6. Motor vehicle traffic on an average autumn weekday in the Helsinki Capital Region (cars/day). Screen capture from the web map service, colors enhanced (Helsingin seudun liikenne 2019; OpenStreetMap contributors 2020).

Table 2. The number of private cars registered in the Helsinki Capital Region municipalities, in KUUMA municipalities, and in Finland total (Statistics Finland 2020a). Private cars decommissioned from traffic are not included in this table.

	2011	2015	2019	Growth 2011–2019
Helsinki	207 639	206 229	214 583	+3.3 %
Espoo	107 833	115 446	122 185	+13.3 %
Vantaa	91 844	98 963	109 068	+18.8 %
Kauniainen	3 815	4 105	4 324	+13.3 %
KUUMA municipalities*	149 930	157 984	169 760	+13.2 %
Finland	2 978 729	3 257 581	3 574 570	+20.0 %

*KUUMA municipalities are the Greater Helsinki municipalities without the Helsinki Capital Region: Hyvinkää, Järvenpää, Kirkkonummi, Kerava, Mäntsälä, Nurmijärvi, Pornainen, Sipoo, Tuusula, and Vihti (KUUMA -seutu liikelaitos 2020).

Table 3. Density of private cars in the Helsinki Capital Region municipalities, in KUUMA municipalities, and in the entire Finland in 2019 (Statistics Finland 2020a, 2020d). Private cars decommissioned from traffic are not included in this table.

	2011			2019		
	Population	Private cars	cars/ 1000 inhab.	Population	Private cars	cars/ 1000 inhab.
Helsinki	595 384	207 639	349	656 970	214 583	327
Espoo	252 439	107 833	427	291 490	122 185	419
Vantaa	203 001	91 844	452	236 434	109 068	374
Kauniainen	8 807	3 815	433	9 990	4 324	433
KUUMA municipalities*	315 094	149 930	476	326 211	169 760	520
Finland	5 401 267	2 978 729	551	5 532 333	3 574 570	646

*KUUMA municipalities are the Greater Helsinki municipalities without the Helsinki Capital Region: Hyvinkää, Järvenpää, Kirkkonummi, Kerava, Mäntsälä, Nurmijärvi, Pornainen, Sipoo, Tuusula, and Vihti (KUUMA -seutu liikelaitos 2020).

The City of Helsinki monitors inbound and outbound motor traffic on several fronts. On an average autumn week day in 2019, the boundary of the municipality was crossed by 662 000 vehicles, inner city boundary by 319 000 vehicles, and Helsinki peninsula boundary by 188 000 vehicles. During the last ten years, motor vehicle crossings of the boundary of Helsinki has increased 6 %. Inner city boundary crossings have increased 11 % while crossings of the Helsinki peninsula have decreased by 21 % (Kostiainen and Moilanen 2020).

In Espoo, motor traffic is monitored on eastern and western municipality boundaries. Facing east, to Helsinki, on average 308 000 vehicles crossed the boundary daily. To the west, to Kirkkonummi and Vihti, daily crossings measured at 93 000 vehicles (Espoon kaupunkisuunnittelukeskus 2020). Compared to the previous year, the cities of Espoo and Helsinki report increases in daily traffic along their boundaries in the range of 1–2 %.

3.3 Data

Essential data for this study was provided by Statistics Finland, the research group Digital Geography Lab of University of Helsinki, the municipalities of Helsinki Capital Region, and Finnish Environment Institute (table 4).

Table 4. Data utilised in the thesis.

Data	Description	Purpose in thesis	Abbreviation in thesis	Citation
CORINE land cover 2018	Land use and land cover data in vector format	Artificial surface data	*CORINE*	Finnish Environment Institute 2018
Helsinki Region Travel Time Matrix 2018	Travel time and distance information for routes between all *grid* cell centroids in the Capital Region of Helsinki	Use in travel time comparison calculations between the *Travel Time Matrix* and thesis survey results	*TTM*	Tenkanen et al. 2018
MetropAccess-YKR-grid	Statistical grid of 250 x 250 meter cells for monitoring urban structure, the Helsinki Capital Region area	Use in travel time comparison calculations between Travel Time Matrix 2018 and thesis survey results	*grid*	Toivonen et al. 2014, Statistics Finland 2020d
Paavo – Open data by postal code area 2018	Helsinki Capital Region postal code areas	Thesis study area and the basic unit of spatial resolution in the survey	*postal*	Statistics Finland 2019
Regional population density 2012	Population density with municipality boundaries	Visualisation (municipality boundaries)	*hcr_muns*	Statistics Finland 2012
Subdivisions of the Helsinki Capital Region	The subdivisions of the municipalities of the Helsinki Capital Region	Visualisation (subdivision boundaries)	*subdivisions*	Helsingin, Espoon, Vantaan ja Kauniaisten mittausorganisaatiot 2011
Zones of urban structure (Yhdyskuntarakenteen vyöhykkeet) 2017	Delineation of urban areas based on the theory of urban fabrics	Data on spatial structure of urban areas	*YKR zones*	Ristimäki et al. 2017

The foundation of this research is the dataset *PAAVO – open data by postal code area* (abbreviated *postal* in this thesis) (figure 17) (Statistics Finland 2019). This data provides a large selection of data regarding the population of every postal code area in Finland. This includes detailed demographics and data about employment by field which follows the industrial classification TOL 2008 (Statistics Finland 2008). However, this thesis only utilises the spatial definitions of the postal code areas, using these polygons to differentiate areas from each other in the web survey. This research makes use of the PAAVO 2018 dataset, released in January 2019.

In this thesis, the *CORINE Land Cover 2018* (abbreviated *CORINE*, figure 7) vector format dataset is used to locate built area, or artificial surface, in the Helsinki Capital Region (Finnish Environment Institute 2018). Provided by Finnish Environment Institute, *CORINE* contains polygonal data about land cover and land use for the entire nation in different hierarchy levels. In this thesis, the hierarchy level 1 value *Artificial surfaces* is used (table 14). The minimum unit depicted in this dataset is 25 hectares in area or 100 meters in width. This slightly coarse data fits well with the spatially simplified nature of the postal code areas. *CORINE* dataset is an integration of automated satellite image interpretation and existing digital map data. In this thesis, every postal code area is given the attribute value of how much, in percentage, of the area is artificial, built surface.

MetropAccess-YKR-grid (abbreviated *grid*, figure 9) is a spatial dataset which consists of cells with the dimensions of 250 by 250 meters ($n = 13231$) (Toivonen et al. 2014). The dataset is used in the MetropAccess project of Digital Geography Lab and is based on the statistical grid dataset provided by Finnish Environment Institute and Statistics Finland (Statistics Finland 2020d). *Grid* is a simple dataset and only contains the attribute data of spatial coordinates of cells and their identifiers, the YKR ID. Using the YKR ID it is effortless to join the *Travel Time Matrix* data with the statistical data provided by Statistics Finland, allowing wide-ranging possibilities for further research. The extent of the dataset is the Helsinki Capital Region.

A main focus in this thesis was to compare the thesis survey results with the *Helsinki Region Travel Time Matrix 2018* (abbreviated *TTM*), a dataset provided by Digital Geography Lab, a research group based in the University of Helsinki, the department of geosciences and geography (Tenkanen et al. 2018). The newest release of their dataset provides travel times for public transport, private car, walking, and bicycling between all *grid* cells. All travel times in this dataset were calculated using the door-to-door approach, which incorporates all parts of a journey from place A to place B into the travel time, including walking from one's home door to the car or bus stop and the time spent searching for parking (Salonen and Toivonen 2013, figure 2). This thesis focuses on journeys made by private car.

All postal code areas in the survey results were classified with the *zones of urban structure* (officially *Yhdyskuntarakenteen vyöhykkeet*, abbreviated *YKR zones*, figure 8) (Ristimäki et al. 2017). Utilising the same statistical grid of 250 x 250 meters as *grid*, *YKR zones* classifies the cells to produce pedestrian, public transport, and automobile zones in and around Finland's urban regions using the theory of urban fabrics. According to this theory, these three zones developed during different times in the urban region's history (Newman et al. 2016). In this thesis, every postal code area is assigned with a class defined in the *YKR zones* based on which class has the largest presence. Adding this data into the survey results aimed to provide more possibilities to explain the hypothetical dissimilarity of survey results in different parts of the Helsinki Capital Region.

The regional division maps of the Helsinki Capital Region (officially *Pääkaupunkiseudun aluejakokartat*, abbreviated *subdivisions*, figure 21) was used in this thesis to analyse and visualise the survey results by subdivisions of the Helsinki Capital Region (Helsingin, Espoon, Vantaan ja Kauniaisten mittausorganisaatiot 2011). Dividing the survey results into subdivisions would potentially give rise to local phenomena which would not be perceptible in the finest available level of spatial resolution, the postal code areas.

The dataset *Regional population density 2012* (figure 21) was used in this thesis to visualise the boundaries of the municipalities in Helsinki Capital Region (Statistics Finland 2012).

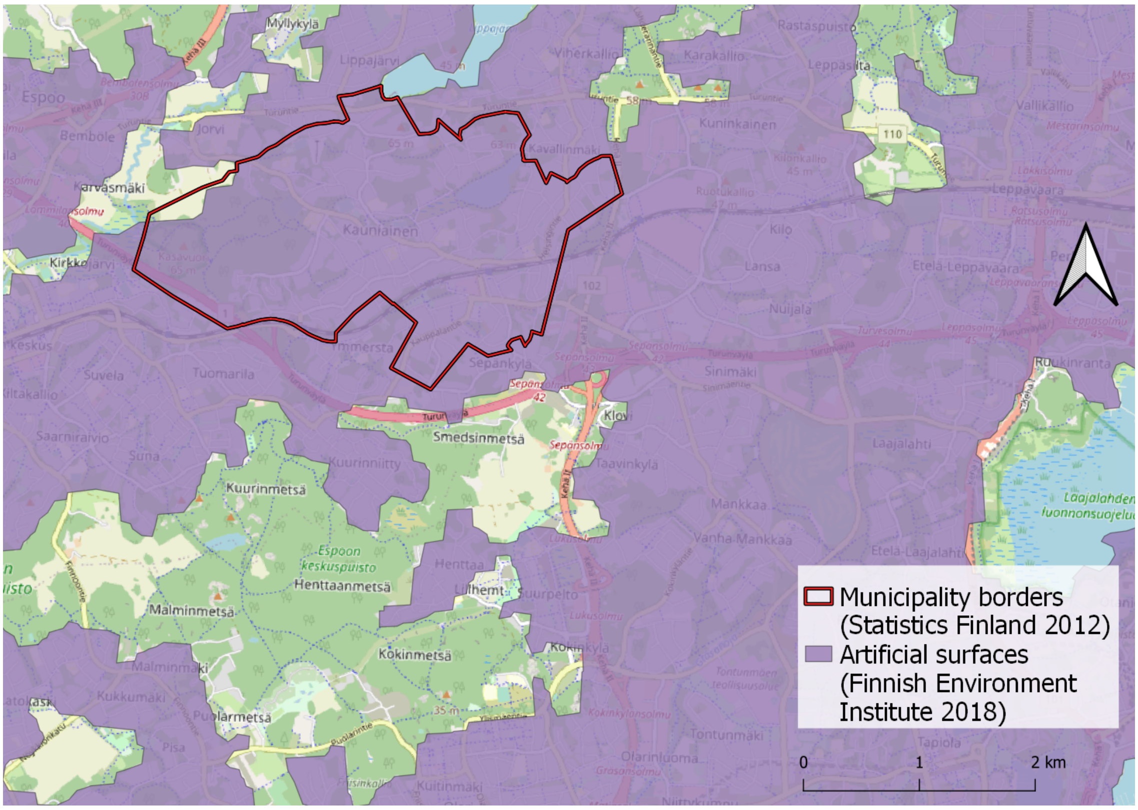


Figure 7. CORINE Land Cover 2018 artificial surfaces in Kauniainen and Eastern Espoo. The minimum unit depicted in this dataset is 25 hectares in area or 100 meters in width (OpenStreetMap contributors 2020).

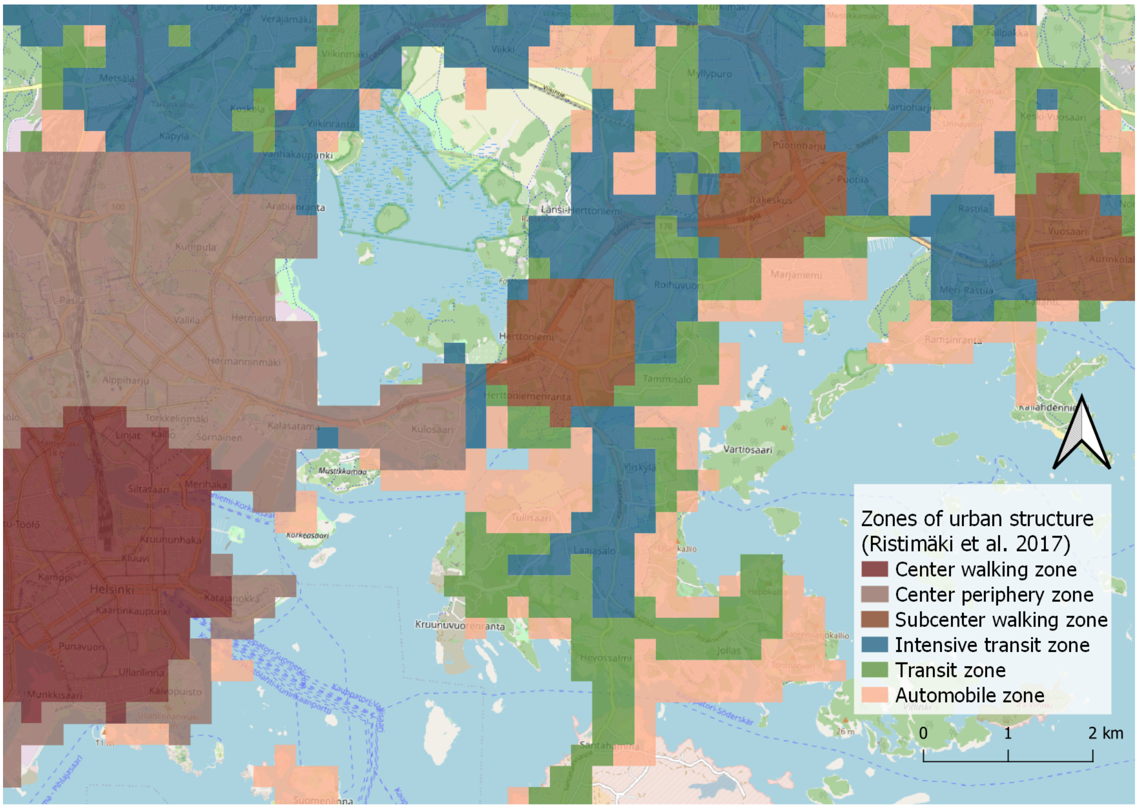


Figure 8. Zones of urban structure, portrayed here in Eastern Helsinki (OpenStreetMap contributors 2020).

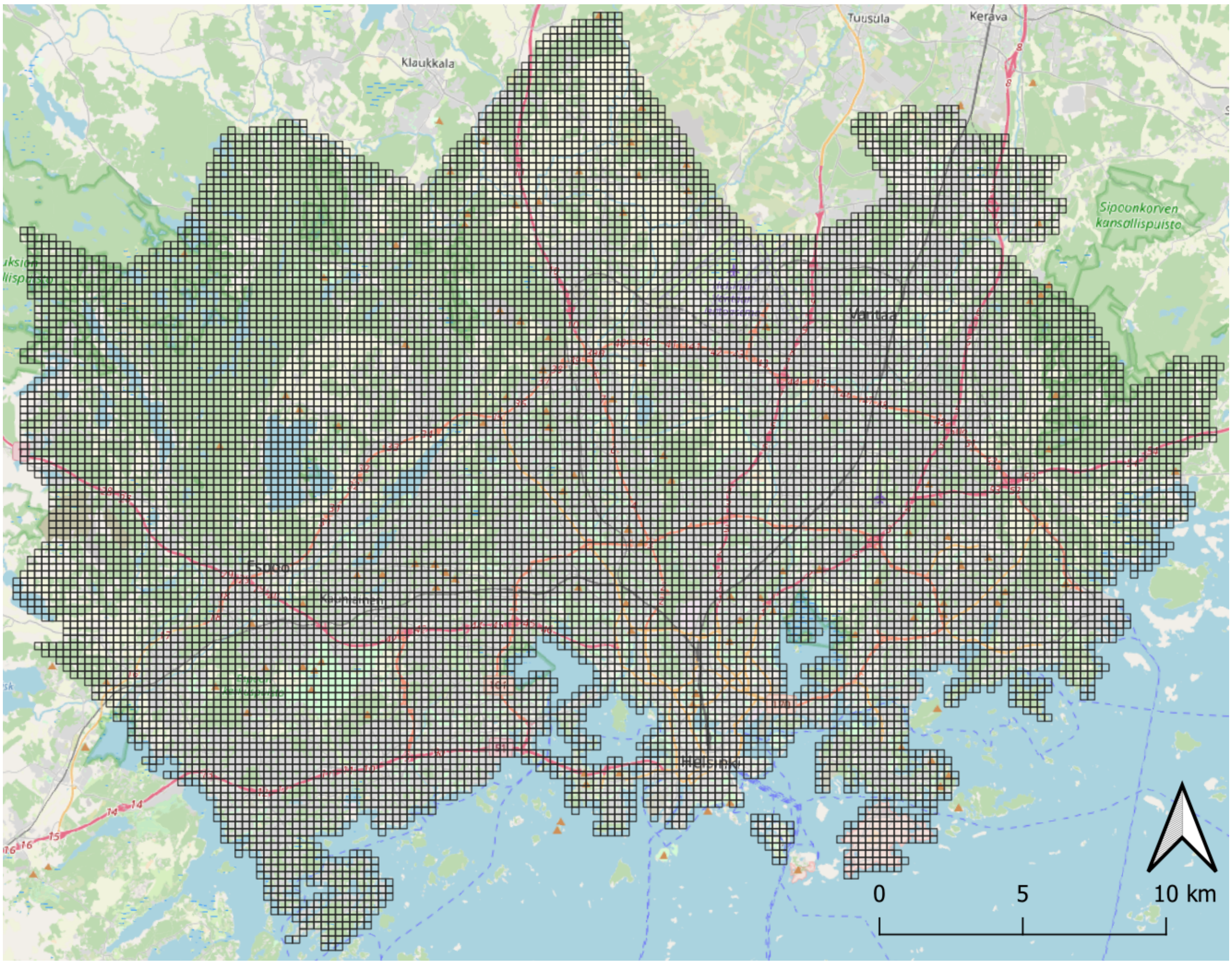


Figure 9. MetropAccess grid GIS layer (OpenStreetMap contributors 2020).

3.4 Software

A wide variety of software was used in the research for this thesis. The research promotes openness and transparency and therefore much of the software employed in this work is free, open-source, or both. The research survey application utilised several essential web technologies such as JavaScript, HTML, CSS and PHP (table 5). Using the web mapping library Leaflet, with the assistance of jQuery and other libraries, a modern and easy-to-use survey web application was created. Server-side, the programming language PHP was used to verify received data.

Data processing was carried out in Python 3.7.6 and R for Windows 3.6.3, with the initial processing done in Python and most of the analysis and visualisation in R (table 5). Much of the work depended on additional software libraries available for the programming languages (table 6). Python Anaconda version 2020.02 – a distribution for Python for statistical computing – provides the majority of the needed software libraries in the installation package, with the notable exception of GeoPandas, a library for geospatial pandas DataFrames in Python, and Shapely, a library for manipulation and analysis of planar geometric objects. In R, many libraries were used to achieve a comprehensive set of descriptive statistics. Libraries such as Shiny, ggplot2, and ggiraph formed the basis of the visualisation of the survey results.

The thesis was written and typeset with LaTeX using the online LaTeX editor Overleaf. LaTeX is a document preparation system, used to create documents such as scientific articles. LaTeX adheres to the WYSIWYM (what you see is what you mean) system, as opposed to the "what you see is what you get" (WYSIWYG) system of text editors such as Microsoft Word, meaning that after establishing a set of parameters LaTeX will automatically compute the document formatting, while the user can concentrate on the document content. While LaTeX can be considered a programming language, it is more closely related to markup languages such as Hypertext Markup Language (HTML). In this LaTeX document, the LaTeX distribution TeX Live 2019 was used. Overleaf supports GitHub integration and as a result the complete thesis is available for viewing in the GitHub repository https://github.com/sampoves/Masters-2020 alongside with its entire development history.

In addition to the aforementioned technologies, the flowcharts in this thesis were created with the web application *diagrams.net*. Most of the map visualisations of this thesis were made using the geographic information system application QGIS version 3.12.2.

Table 5. Programming languages, essential technologies, and Integrated development environments (IDE) utilised in the thesis, grouped by the function in this thesis.

Programming language and IDE	Description	Purpose in thesis	Citation
JavaScript, HTML, CSS (NetBeans 8.2.0)	Essential web technologies	Research survey programming, analysis and visualisation application programming	WHATWG 2020, W3C 2020, ECMA 2019, Apache Software Foundation 2016
Python 3.7.6, Anaconda 2020.02 (Spyder 4.0.1)	Anaconda is a Python distribution for scientific computing	Survey data processing	Van Rossum and Drake 2009, Anaconda Inc. 2020, Spyder Project Contributors 2020
R for Windows 3.6.3 (RStudio 1.2.5033)	Programming language environment for statistical computing	Survey data analysis and visualisation	R Core Team 2020, RStudio Team 2015
LaTeX (Overleaf)	Document preparation system	Thesis formatting, structure, and writing	Writelatex Limited 2020

Table 6. Essential software libraries used in the thesis.

Programming language	Software package	Description	Citation
JavaScript	Leaflet 1.4.0	Web mapping library for the research survey	Agafonkin 2019
	jQuery 3.4.1	Simplification of HTML DOM traversal and other features	The jQuery Foundation 2020
	Font Awesome 5.13.0	Font and icon collection	Fonticons, Inc. 2020
Python	pandas 1.0.1	Data analysis and manipulation	McKinney 2011
	GeoPandas 0.5.0	Geographic data operations	GeoPandas developers 2019
	Shapely 1.6.4.post1	Geometric objects, predicates, and operations	Gillies 2019
	rtree 0.8.3	Spatial indexing	Gillies and Butler 2014
R	Shiny 1.4.0.2	Web application framework for R	Chang et al. 2019
	ggplot2 3.3.0	Data visualisation	Wickham 2016
	ggiraph 0.7.0	Interactive ggplot2 graphics	Gohel and Skintzos 2019
	dygraphs 1.1.1.6	Interactive time series charting	Vanderkam et al. 2018
	fst 0.9.2	High-performance writing and loading of data	Klik 2020

3.5 Methods

3.5.1 Programming the parking survey

To achieve maximum transparency and repeatability for this research, in addition to freedom in survey content and appearance, a survey web application was programmed from the ground up utilising HTML, JavaScript and PHP. The survey and its supporting infrastructure was installed on a virtual machine in CSC's – the state owned ICT solutions company – Taito supercluster. CSC offers virtual machines in several different hardware configurations, or flavors. The virtual machine flavor picked for this survey was *standard.medium*, a flavor with 3.9 gigabytes RAM, three virtual CPUs and 80 GB of disk space. Running on the Linux distribution Ubuntu version 16.04, the backbone of the survey ecosystem was a LAMP stack (Linux, Apache, MySQL, PHP), a software bundle which incorporates the Linux operating system, Apache web server software, MySQL relational database management system and the PHP programming language environment for server-side scripting. The public component of the survey is the front-end, the only component of the survey system a respondent would interact with (figure 10). One may use additional software in a LAMP stack for extended functionality or can replace some of the components with a wide array of alternatives. This thesis utilises the components described in the table 7.

Figure 10. The parking survey web application's welcoming dialog window. This application can be tested at https://parking-survey.socialsawblade.fi.

Table 7. The research survey web application components (LAMP stack).

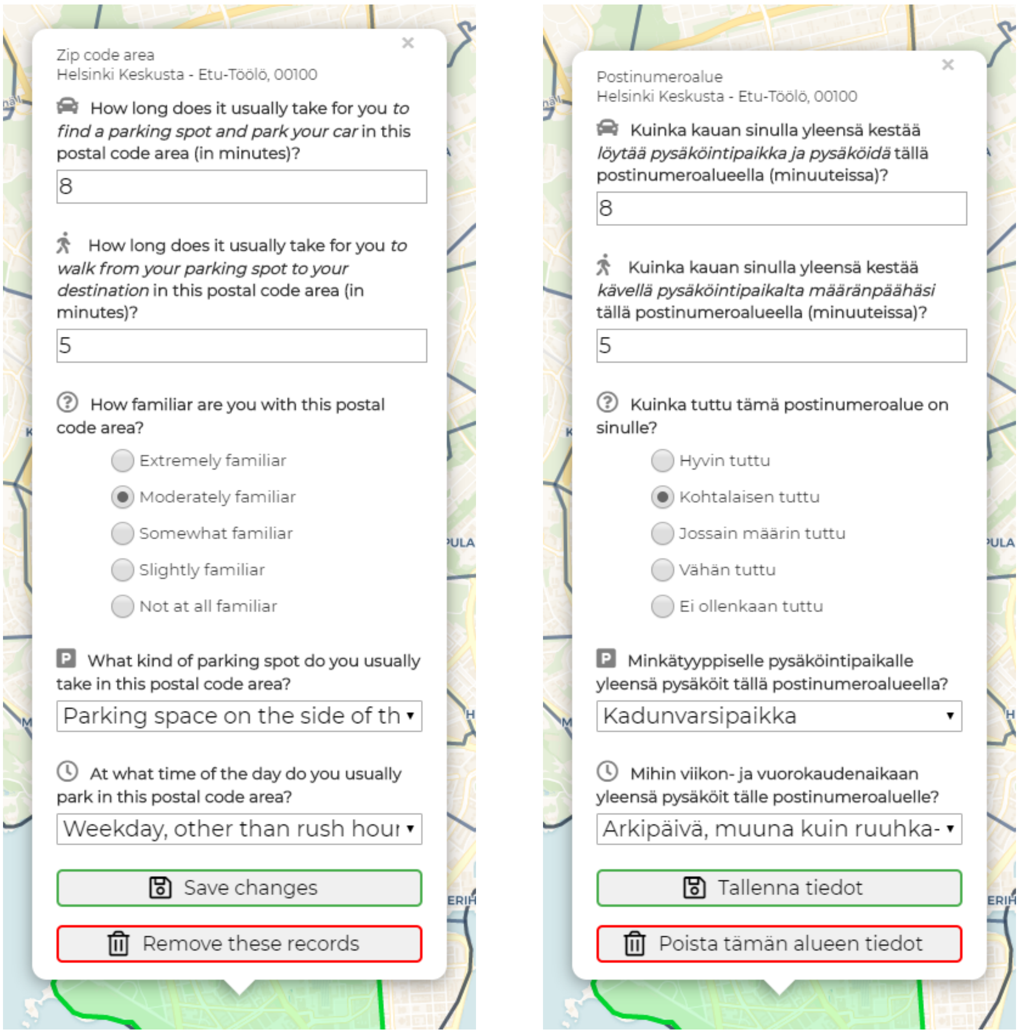
Component	Version	Description
Ubuntu	16.04.6	Linux distribution, the operating system for the virtual machine
Apache HTTP Server	2.4.18-2ubuntu3.9	Web server software, management of website requests and responses
MySQL	5.7.25-0ubuntu0.16.04.2	Relational database management system, survey database operations
PHP	7.0.33-0ubuntu0.16.04.1	Programming language, used for server side scripting
Parking survey front-end	16.5.2019	Survey visible to user, graphical user interface

Setting up the virtual machine for the use of the survey was a process of a few stages. The LAMP stack was installed on the fresh virtual machine. After the successful installation, the MySQL tables were formed and relevant users created. The last step before a fully functioning web server was using root access to give the survey components permission to access relevant system directories. The parking survey's GitHub repository (https://github.com/sampoves/parking-in-helsinki-region) may be viewed for the full step-by-step install procedure used to set up the web server for this survey research.

The survey front-end was programmed in NetBeans IDE 8.2 in mostly JavaScript using an open-source mapping library Leaflet (software version 1.4.0) in January–May 2019. In the survey, the respondent was presented with a map view of the Helsinki Capital Region with its 167 postal code areas with the ability to drag the view, zoom in and out, search for places and addresses, choose the language between English and Finnish, and tweak various other settings to their liking. In this web survey, the respondent was asked to pick as many postal code areas as they could remember parking in in the last two years, and answer to five questions per each postal code area (table 8 and figure 11). In each question, the respondent was asked to estimate their parking experience in that postal code area usually during the past two years. The last two years was chosen as the timeframe to allow respondents to comfortably recall parking events which happened during the subjective notion of "recent memory" while also forbidding the submission of out of date parking times.

Table 8. Survey questions and question choices.

Question	Question choices	Abbreviation
How long does it usually take for you to find a parking spot and park your car in this postal code area (in minutes)?	0–99	`parktime`
How long does it usually take for you to walk from your parking spot to your destination in this postal code area (in minutes)?	0–99	`walktime`
How familiar are you with this postal code area?	1 – Extremely familiar 2 – Moderately familiar 3 – Somewhat familiar 4 – Slightly familiar 5 – Not at all familiar	`likert`
What kind of parking spot do you usually take in this postal code area?	1 – Parking space on the side of the street 2 – Parking lot 3 – Parking garage 4 – Private or reserved spot 5 – Other	`parkspot`
At what time of the day do you usually park in this postal code area?	1 – Weekday, rush hour (07.00–09.00 and 15.00–17.00) 2 – Weekday, other than rush hour 3 – Weekend 4 – None of the above, no usual time	`timeofday`



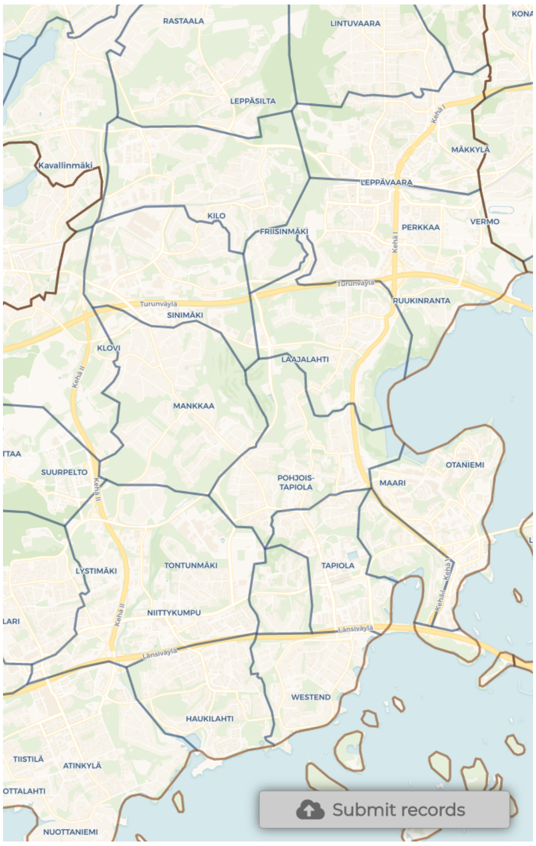
(a) Survey questions in English.

(b) Survey questions in Finnish.

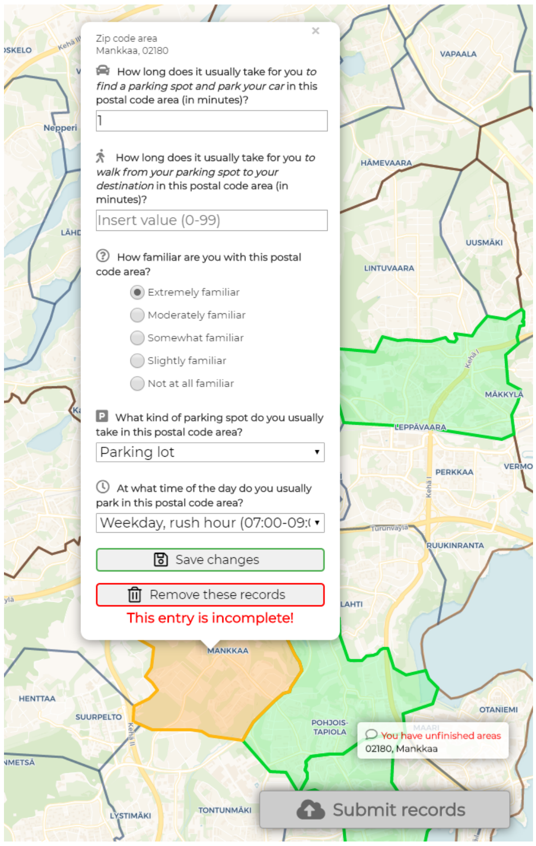
Figure 11. For each postal code area of their choosing the respondent would answer to these five questions. The survey was made available in English and Finnish.

The maximum values for searching for parking and walking to destination were consciously placed to 99 in an effort for the range to not feel restrictive for the survey respondent.

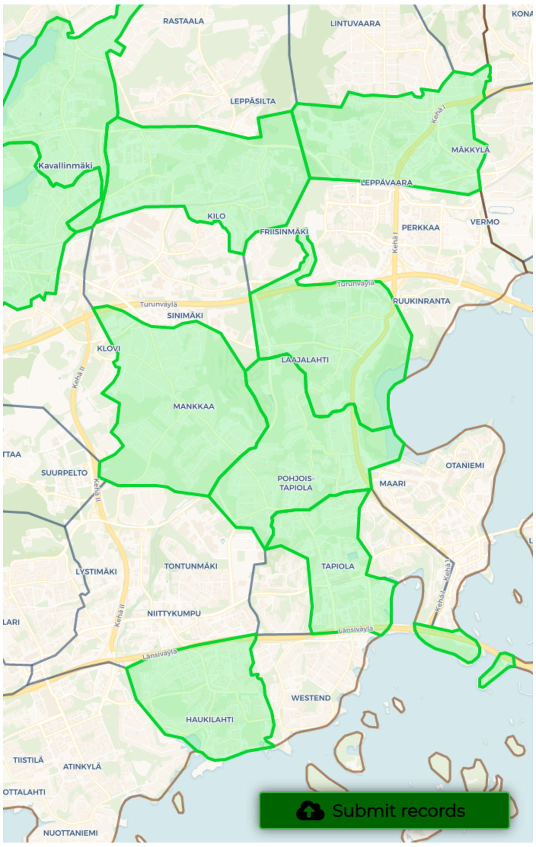
In the introduction to the survey, it was explained to respondents that all answers were meant to be estimates as the survey was not about an exact time and place. To mitigate confusion and errors made by respondents, a comprehensive help functionality and a location search tool were implemented in the parking survey. Once the respondent was finished with the survey, they would send their responses to the server. Respondents were welcomed to return to the survey to send additional data on any postal code areas they had missed the last time. Figure 12 visualises the the steps respondents would follow to send their data in the survey application.



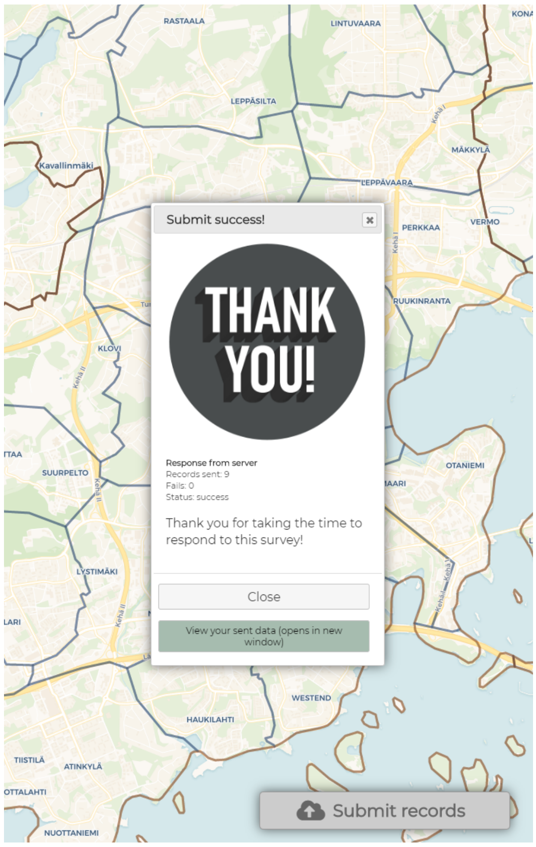
(a) Respondent arrives to the survey web application to see a map with the postal code areas of the Helsinki Capital Region lined out.



(b) Respondent proceeds to fill out their parking experiences in freely chosen postal code areas.



(c) *Submit records* button activates when all questions in all selected postal code areas are completed.



(d) Respondent receives a prompt to confirm that their submission was successful.

Figure 12. A respondent would follow these steps to submit data through the survey web application.

When data was received from the respondent, a script written in PHP verified the data contents. This was an effort to prevent attacks on the web server running the study survey. Only specific variables of specific types were accepted from the front-end. Additionally, the PHP verification made sure falsified or incomplete data would not be accepted into the database containing the verified results. If the server-side verification test failed in any way, the respondent was informed about it.

In addition to the data verification, a PHP script tracked the IP addresses which accessed the survey web server. By using the survey, respondents agreed that their IP addresses were recorded for the use of this thesis solely to identify falsified or overlapping data and detect unique visits. All IP addresses were anonymised with a Python script and original sensitive was data deleted. The anonymisation script is available for viewing at the thesis data analysis repository at GitHub (https://github.com/sampoves/thesis-data-analysis).

As a final survey component, the server side contained two MySQL datatables, one for received data (table 9) and another for survey web page hits (table 10). In the table *records*, the following data was recorded: time of sending (column name `timestamp`), IP address (`ip`), postal area code (`zipcode`), a value in the sequence 1–5 for the likert question (`likert`), a value in the sequence 1–5 for the question what type of parking spot was used (`parkspot`), an integer value for how long it usually took to park in this location (`parktime`), an integer value for how long it usually took to walk from parking place to one's destination (`walktime`), and a value in the sequence 1–4 for the question at what time of the day one usually parks in the location (`timeofday`) (table 11). In the table *records*, it is notable that in the case a respondent sent the web server data for multiple postal code areas, each of the postal code areas would take up their own row in the data table. Consequently, it was theoretically possible for one respondent to simultaneously submit 167 rows of data.

In the table *visitors*, the following data was recorded: IP address (`ip`), the timestamp of the first visit of this IP address (`ts_first`), the timestamp of the latest visit of this IP address (`ts_latest`), and the count of visits (`count`). In this table, an IP address is only stored once. On the first visit of an IP address, the row for that IP address is created in the data table with `ts_first` and `ts_latest` being identical. On further visits of that IP address the original row is appended with updated information in the columns `ts_latest` and `count` (table 12).

Table 9. An excerpt of the data content of the research survey MySQL table *records*.

id	timestamp	ip	zipcode	likert	parkspot	parktime	walktime	timeofday
3245	2019-06-06 21:41:21	wro4qo8hv4	00510	1	4	0	3	1
3246	2019-06-06 21:41:54	aonm72lyx3	00520	2	1	10	5	1
3247	2019-06-06 21:46:19	n1982i4i2v	00100	1	1	20	4	1
3248	2019-06-06 21:46:22	sbhfz0uvsl	00210	1	1	5	3	3
3249	2019-06-06 21:46:22	sbhfz0uvsl	00220	2	2	5	5	2

Table 10. An excerpt of the data content of the research survey MySQL table *visitors*.

id	ip	ts_first	ts_latest	count
1780	mvovd467a7	2019-05-26 15:25:23	2019-05-26 15:26:06	2
1781	xgbgkkzxb3	2019-05-26 15:26:23	2019-05-26 15:26:23	1
1782	c9qer4q99a	2019-05-26 15:27:25	2019-05-26 15:27:25	1
1783	cujhd0hng7	2019-05-26 15:27:29	2019-05-26 15:27:29	1
1784	3ja7gjtko6	2019-05-26 15:28:45	2019-05-26 15:29:20	2

Table 11. The structure of the survey MySQL table *records* fetched with the statement `DESCRIBE records;`

Field	Type	Null	Key	Default	Extra
id	int(11)	No	PRI	NULL	AUTO_INCREMENT
timestamp	varchar(19)	Yes		NULL	
ip	TEXT	Yes		NULL	
zipcode	varchar(5)	Yes		NULL	
likert	int(1)	Yes		NULL	
parkspot	int(1)	Yes		NULL	
parktime	int(2)	Yes		NULL	
walktime	int(2)	Yes		NULL	
timeofday	int(1)	Yes		NULL	

Table 12. The structure of the survey MySQL table *visitors* fetched with the statement `DESCRIBE visitors;`

Field	Type	Null	Key	Default	Extra
id	int(11)	No	PRI	NULL	AUTO_INCREMENT
ip	TEXT	Yes		NULL	
ts_first	DATETIME	Yes		NULL	
ts_latest	DATETIME	Yes		NULL	
count	int(11)	Yes		NULL	

The parking survey was released to the public in May 2019 and the active phase of collecting data continued until 30 June 2019. However, the survey remained open after this active period, receiving the last row of data in October 2019. The majority of the respondents were found through Facebook groups. Invitations to participate in the survey were sent to 113 city district and neighborhood groups with a theoretical reach of tens of thousands of people. Of the 113 posts, 63 were Helsinki centric groups, while 23 were based in Espoo, 15 in Vantaa, and 12 in municipalities bordering the Helsinki Capital Region. In addition to these city district and municipal groups, invitations to participate were sent to two other Facebook groups, "Lisää kaupunkia Helsinkiin", a group for city planning ethusiasts in Helsinki, and the GIS profession group "GIS-velhot". In addition to Facebook, an effort was also made to get faculty members of geosciences and geography and students of University of Helsinki to participate in the survey. A small amount of answers were collected with a tweet sent from the Twitter account of Digital Geography Lab. After the initial invitation to participate, reminders were sent to the largest Facebook groups one month after the original posts.

Viewing figure 13, some response patterns arise when viewing gathered responses as a cumulative chart. It must be acknowledged that it is not possible to conclusively differentiate from which group or city the survey data originated from. This being said, the figure shows that the survey invitation is rapidly buried in the feeds of respective groups and most responses happened immediately after posting the invitations. From the figure 13 it may be observed that the Facebook groups have been very effective in gathering responses, while other channels, such as advertisements on Twitter and University of Helsinki email lists have been less so. The invitation posts on Facebook were sent over multiple days to the groups roughly in the following order:

Espoo → Helsinki → Vantaa → bordering municipalities → reminders to the largest groups

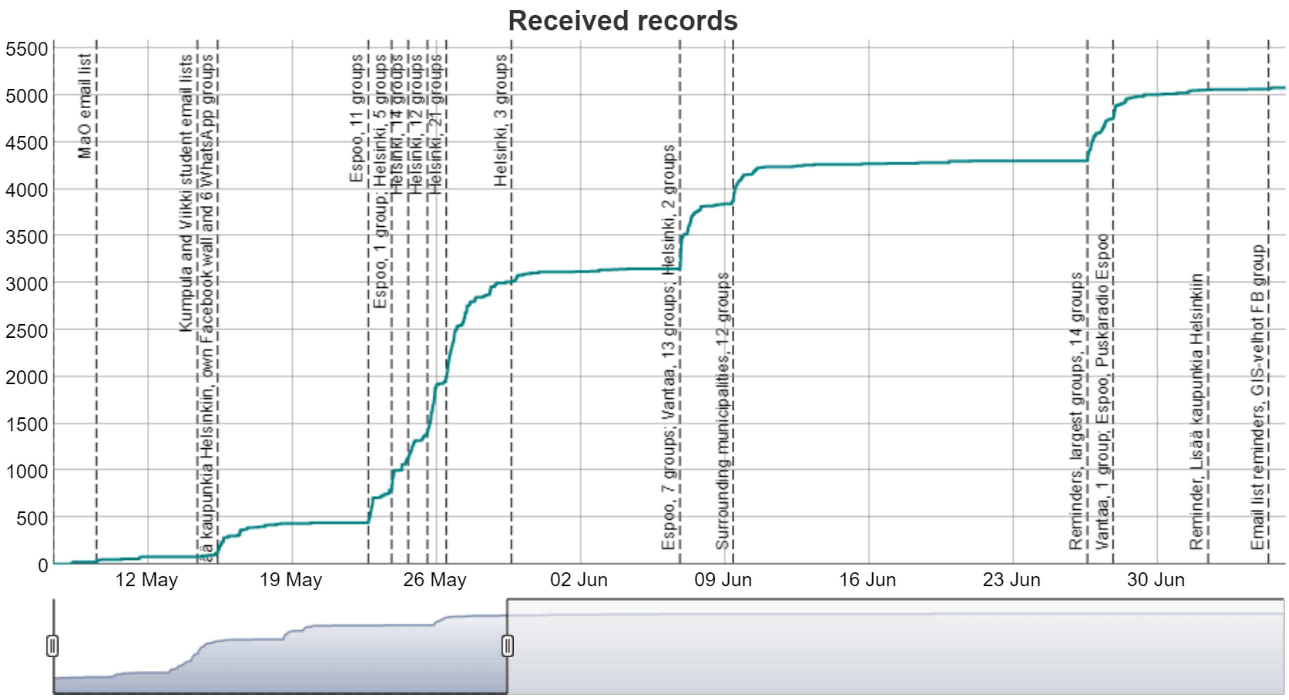


Figure 13. Received survey responses viewed cumulatively over time. This view show the active collection phase in the early summer 2019. Screen capture from the *visitors* analysis application.

The source code for the survey described in this chapter and step-by-step information to set up an identical system is available at GitHub (https://github.com/sampoves/parking-in-helsinki-region). As a side product, a variant of this survey was created where respondents pick precise points instead of areas. This point-based survey template is, too, available at GitHub (https://github.com/sampoves/leaflet-map-survey-point). The parking survey web application as it was used in this thesis may be tested in the following web address: https://parking-survey.socialsawblade.fi.

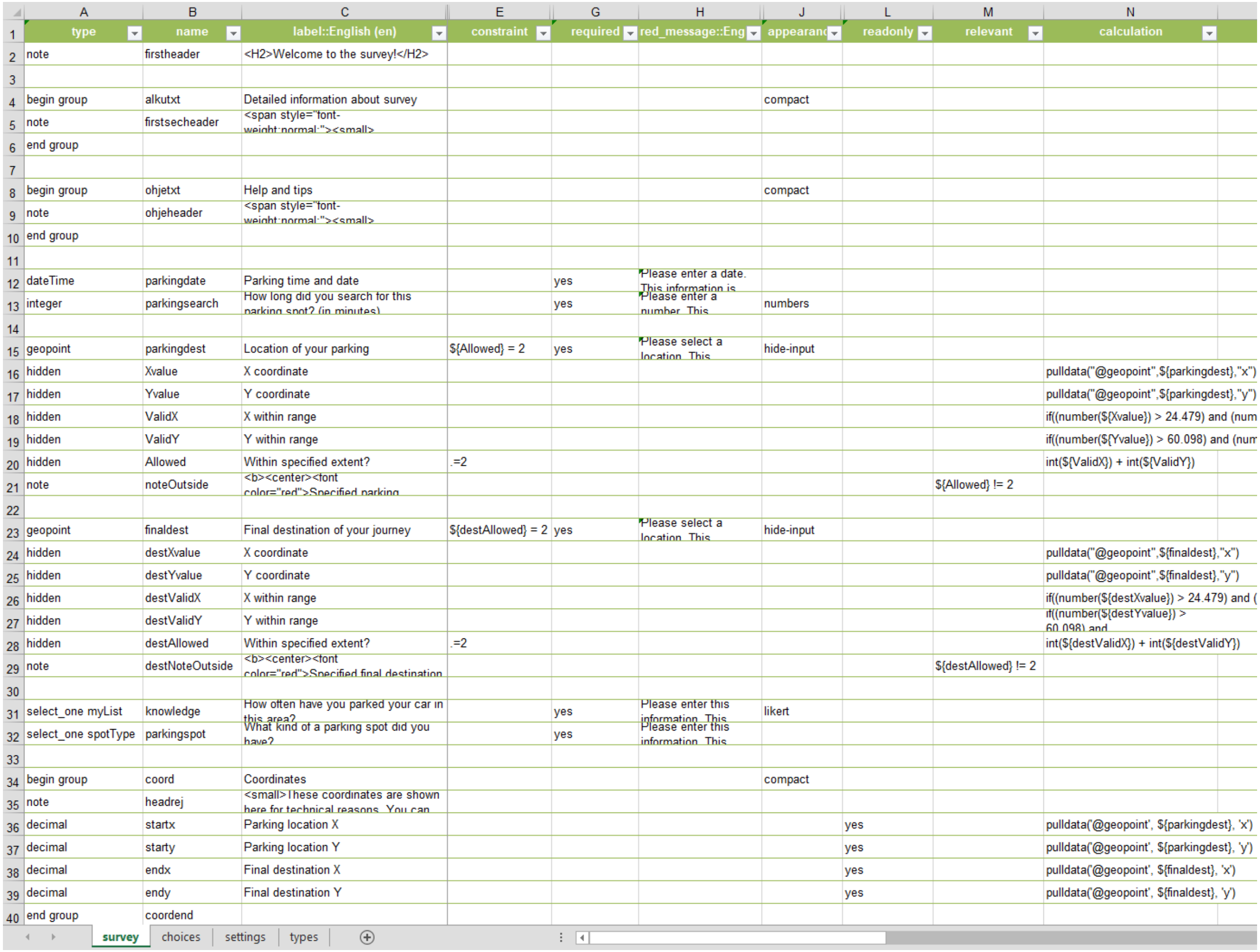
3.5.2 Other approaches that were considered

To collect the areal parking data, the study required an interactive survey which respondents could use to submit their parking habits in a spatial fashion. To attract the largest possible number of submissions, the survey also needed to be of modern design, easy to use and its purpose easy to understand. The survey would have to be clear-cut, effortless to internalise and short in length as to prevent users getting frustrated and leaving before submitting answers. Design-wise, the spatial resolution of the survey was in question. The particular concern was that in the case of insufficient amount of answers, what kind of area delineation would be at the same time detailed enough but also streamlined enough to realistically reach results of good quality? This chapter describes the process that would lead to the implemented web survey to accentuate the challenges this kind of research entail. The prototyping of the park survey followed these three steps:

1. Review of the available ready-made map survey platforms;
2. Development of the prototype map survey on Survey123, and;
3. Programming of the parking survey used in this research.

In the beginning of the process, a review of ready-made map survey platforms was conducted. It quickly became apparent that there were few alternatives available and even fewer free, sufficiently customisable alternatives. Out of the proprietary options, Maptionnaire by the Finnish company Mapita was considered. However, their fee was considered too steep and Maptionnaire was passed on.

Next Survey123 for ArcGIS was evaluated. An Esri operated service, Survey123 is used to create and analyse form based surveys (Esri 2018). It is included in the contract between the University of Helsinki and Esri and thus was free to use for the study. One can quickly design a survey at the Survey123 website and share it immediately to respondents. Alternatively, the service is available as a desktop client, the Survey123 Connect, where Survey123 offers a wider range of possibilities for customisation with its adherence to the XLSForm standard. XLSForm is a standard to make authoring forms in Microsoft Excel easier. With the customisability of XLSForm, users can design Survey123 surveys to the dot while employing the support for Excel style scripting for complex survey behaviour (figure 14). Furthermore, Survey123 provides online tools for collaboration, analysis, and data viewing with many options for exporting the collected data.



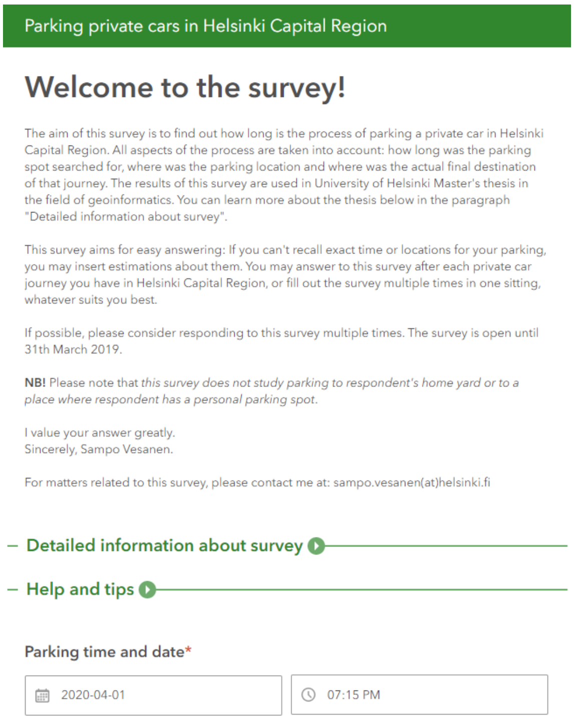
	A	B	C	E	G	H	J	L	M	N
1	type	name	label::English (en)	constraint	required	red_message::Eng	appearanc	readonly	relevant	calculation
2	note	firstheader	<H2>Welcome to the survey!</H2>							
3										
4	begin group	alkutxt	Detailed information about survey				compact			
5	note	firstsecheader	<span style="font-weight:normal;"><small>							
6	end group									
7										
8	begin group	ohjetxt	Help and tips				compact			
9	note	ohjeheader	<span style="font-weight:normal;"><small>							
10	end group									
11										
12	dateTime	parkingdate	Parking time and date		yes	Please enter a date. This information is				
13	integer	parkingsearch	How long did you search for this parking spot? (in minutes)		yes	Please enter a number. This	numbers			
14										
15	geopoint	parkingdest	Location of your parking	${Allowed} = 2	yes	Please select a location. This	hide-input			
16	hidden	Xvalue	X coordinate							pulldata("@geopoint",${parkingdest},"x")
17	hidden	Yvalue	Y coordinate							pulldata("@geopoint",${parkingdest},"y")
18	hidden	ValidX	X within range							if((number(${Xvalue}) > 24.479) and (num
19	hidden	ValidY	Y within range							if((number(${Yvalue}) > 60.098) and (num
20	hidden	Allowed	Within specified extent?	.=2						int(${ValidX}) + int(${ValidY})
21	note	noteOutside	<b><center><font color="red">Specified parking						${Allowed} != 2	
22										
23	geopoint	finaldest	Final destination of your journey	${destAllowed} = 2	yes	Please select a location. This	hide-input			
24	hidden	destXvalue	X coordinate							pulldata("@geopoint",${finaldest},"x")
25	hidden	destYvalue	Y coordinate							pulldata("@geopoint",${finaldest},"y")
26	hidden	destValidX	X within range							if((number(${destXvalue}) > 24.479) and (
27	hidden	destValidY	Y within range							if((number(${destYvalue}) > 60.098) and
28	hidden	destAllowed	Within specified extent?	.=2						int(${destValidX}) + int(${destValidY})
29	note	destNoteOutside	<b><center><font color="red">Specified final destination						${destAllowed} != 2	
30										
31	select_one myList	knowledge	How often have you parked your car in this area?		yes	Please enter this information. This	likert			
32	select_one spotType	parkingspot	What kind of a parking spot did you have?		yes	Please enter this information. This				
33										
34	begin group	coord	Coordinates				compact			
35	note	headrej	<small>These coordinates are shown here for technical reasons. You can							
36	decimal	startx	Parking location X					yes		pulldata('@geopoint', ${parkingdest}, 'x')
37	decimal	starty	Parking location Y					yes		pulldata('@geopoint', ${parkingdest}, 'y')
38	decimal	endx	Final destination X					yes		pulldata('@geopoint', ${finaldest}, 'x')
39	decimal	endy	Final destination Y					yes		pulldata('@geopoint', ${finaldest}, 'y')
40	end group	coordend								

survey | choices | settings | types

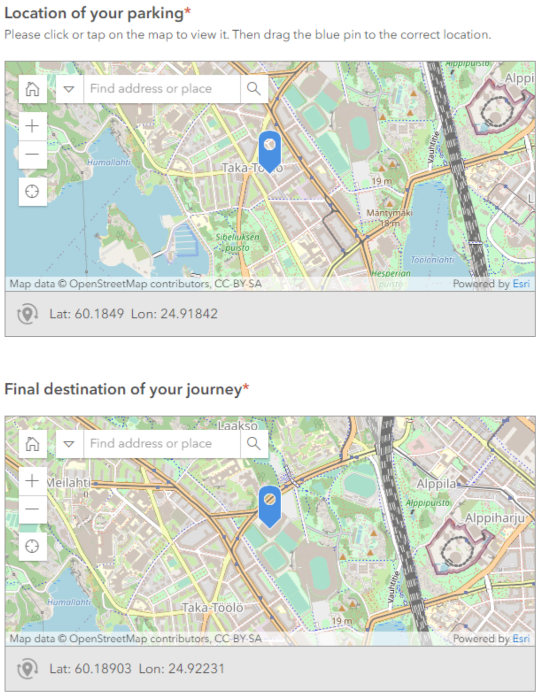
Figure 14. Survey123 XLSForm view in Microsoft Excel. Some parameter columns here are hidden to provide a view to the essential inner workings of the Survey123 form.

At its core, this survey asked respondents for specific parking events in the Helsinki Capital Region they had had (figure 15). Respondents would pick an exact location on a map view for the location of their parked car and separately on a second map view the location of their final destination they had reached on foot. In addition, respondents would fill the date and time of this parking event, how long it took for them to find this parking spot, how often they had parked to that area, and what kind of a parking spot they had taken. Respondents were asked repeat this process as many times as they had the will to do so.

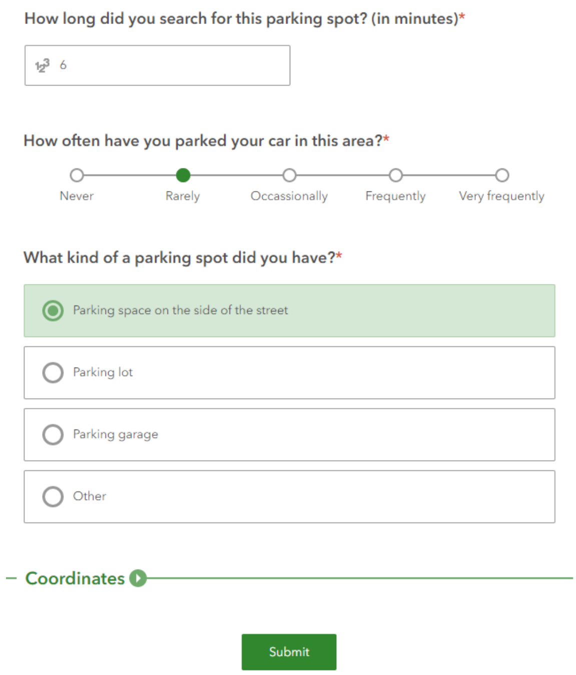
The Survey123 survey was designed to reach the same spatial resolution as the Travel Time Matrix 2018 with its MetropAccess-YKR-grid (abbreviated *grid*, cell dimensions 250 x 250 meters). Using exact coordinates of parkings and final destinations, it would have been possible to allocate each event to possibly two different *grid* cell codes, reaching excellent spatial resolution. As *grid* contains 13 231 cells, there was not enough resources for this master's thesis research survey to accumulate events for every grid cell, or even for most grid cells. If the data gathering campaign had ended with insufficient amount of parking events, the backup plan was to employ an interpolation algorithm to generate approximate boundaries, contour lines, for the hypothetically varying parking search times in the Helsinki Capital Region. It was also considered that the exact coordinates of the parking events could be generalised to other boundaries, such as administrative areas like municipality subdivisions or postal code areas.



(a) Survey introduction and the date and time for the parking event.



(b) Map panels for the parking location and the final destination.



(c) Final questions of the survey.

Figure 15. An example parking event entered into the prototype parking research survey made with Survey123 Connect.

In January 2019, the prototype parking survey developed with Survey123 was deployed to friends and family, with a large scale marketing push on social media platforms planned for later. This original launch tested the feasibility of the collection of such high resolution Public Participation Geographic Information System (PPGIS) data with the highly limited resources available to me. And, indeed, the survey proved itself unwieldy for the purposes of this research. The Survey123 software was difficult to use because of an assortment of inconvenient design choices, unfinished functionality and a helping of software bugs. It was not possible, for example, to have respondents enter multiple parking events at once in a full screen map view. They would have to create a single parking event, send it, and then reload the survey to start from the beginning – something a majority of prospective respondents would not have the patience for. Survey123 Connect version available at the time, 3.1.126, did not allow customisation of the post-submission message and therefore it would not be possible to efficiently direct respondents back to the form. In addition, recording coordinates from two map views was only possible through a bypass. The coordinates of the final destination would have to be printed on the form (hence the section "Coordinates" on the form in figure 15) and then these second set of coordinates could be saved into the survey data table in string format. The technical limitations of Survey123 as a spatial survey were witnessed also in the fact that it was not possible to add custom polygons on top of the map views. It was therefore impossible to delineate the study area for the respondents and accurately detect attempts to add parking events outside of the Helsinki Capital Region.

The functionality of the survey form was not reliable on the most popular web browsers such as Google Chrome and Apple Safari. Survey123 supported multi-language strings but it proved problematic to ensure that the form would open in the system language of most respondents, Finnish. In addition to this, the field for entering the specific time for the parking event was restricted to the 12 hour clock preferred in the United States – a time convention the target group of this thesis would frown upon. To make matters worse, at that time there was a long persisting bug in Survey123 which produced unexpected behaviour, in some cases, with the use of `constraint`, the parameter that controls which entered values are deemed illegal and which are not (GeoNet - The Esri Community 2018). If any type of constraint statement was added, the finalised form would always claim that the related question input was invalid. The parameter would have to be left empty and therefore it was not possible to automatically prevent insertion of parking events happening in the future and excessively long times for searching for parking, reducing the quality of the survey data and making the survey form more confusing for the respondent.

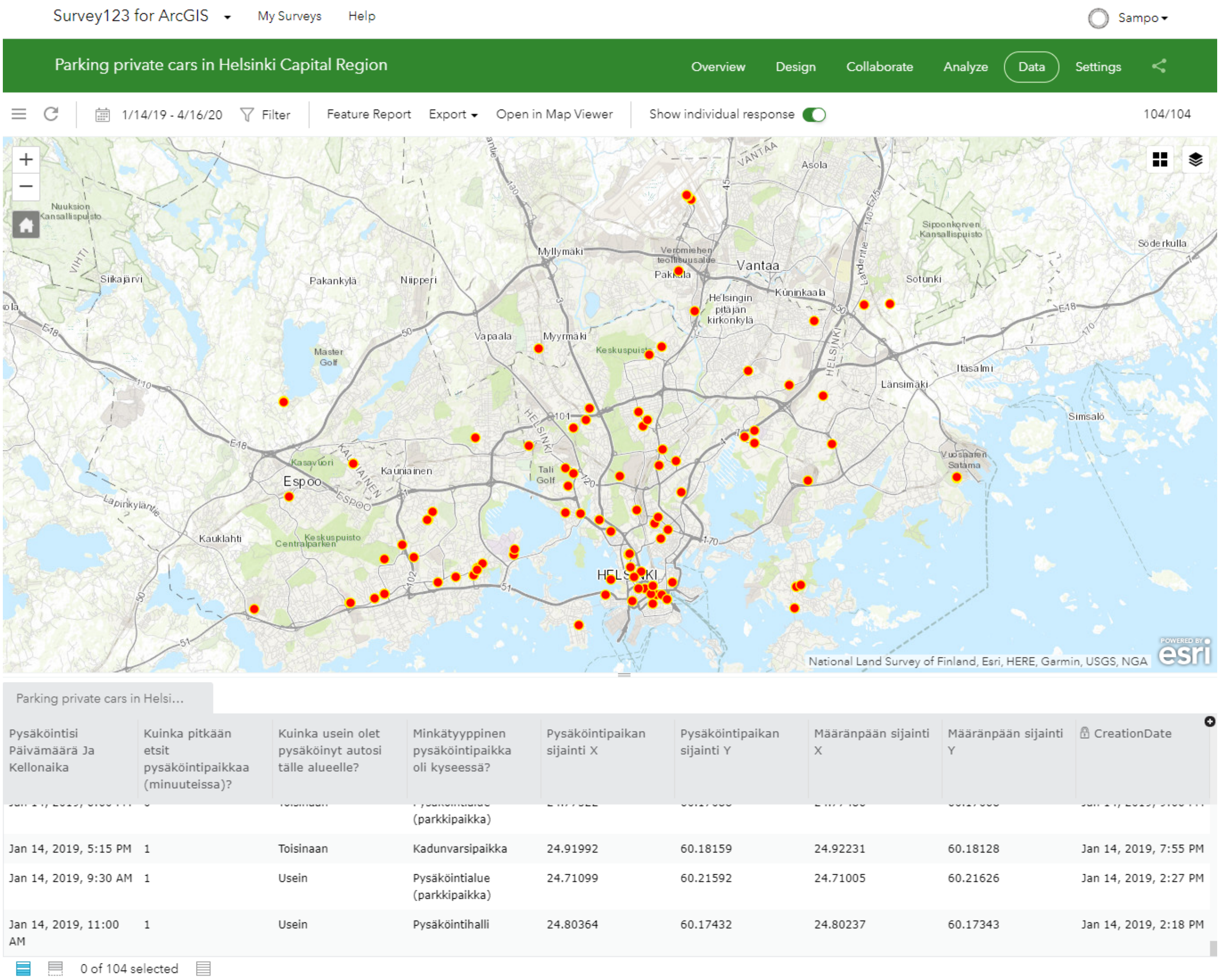


Figure 16. Survey123 for ArcGIS, "data" tab view on the application website. The prototype research survey made with Survey123 received in total 104 parking events. The red dots are the final destinations of each parking event.

Despite the many technical uncertainties of Survey123, the prototype survey gathered more than one hundred parking events in one month (figure 16). This amount was achieved for the most part without advertising. Soon after the publication of the Survey123 parking survey it was decided, however, that the spatial resolution for this research would need to be lower than exact points in an attempt to gather more responses from the entire study area. There is support for lower spatial resolution in PPGIS literature. Exact pinpointing can be viewed as counter-productive, as it may exceed respondents' capacity for area identification, thus bringing about greater spatial error (Brown 2012). An additional deciding factor was the fact that with Survey123, respondents could not send multiple parking events with one survey session, making the form unwieldy and outdated in its rigid structure. It was argued that a more general scale would still be accurate enough to provide good data and a more generalised scale would make the survey easier to answer to and a more pleasant experience for the respondent. Postal code areas were deemed an acceptable compromise in spatial detail.

After careful consideration, it was decided that the actual survey for this thesis would be programmed from the ground up.

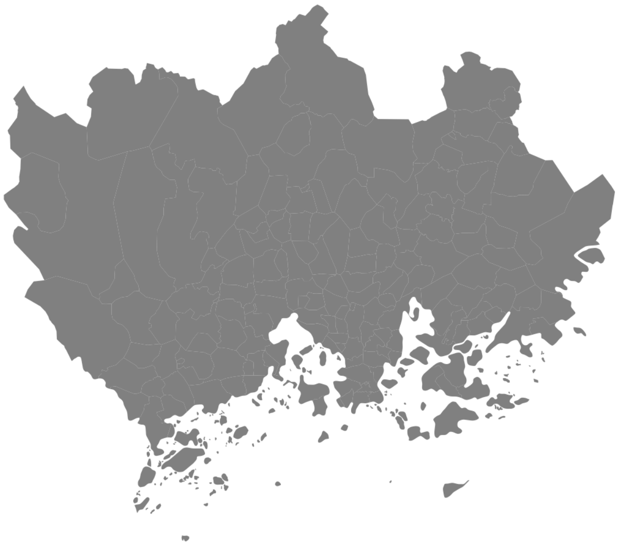
3.6 Processing survey data

In this section, various data are referred to with abbreviated names as this makes it easier to follow the data processing workflow. Please see table 4 for the key.

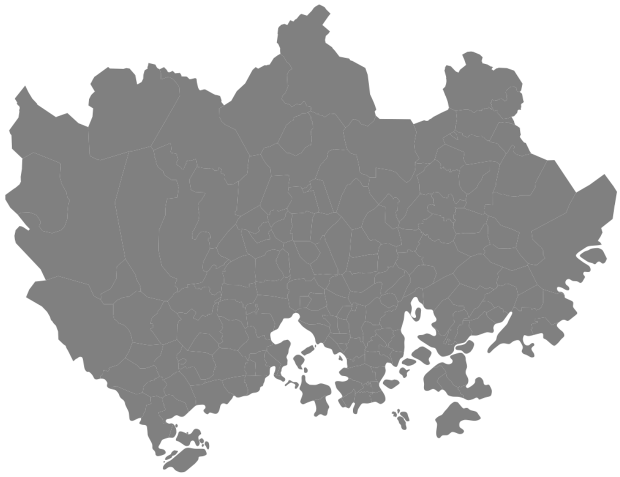
The main objective of the thesis data processing was to merge survey responses dataset (*records*) with selected spatial data and prepare *records*, survey visits dataset (*visitors*), PAAVO postal code areas dataset (*postal*), and MetropAccess-YKR-grid (*grid*) for later analysis in R programming language environment. Using a selection of open spatial data (table 4), new explanatory variables would be available for use in the analysis. This opened opportunities to compare the newly gathered survey data against that in the Helsinki Region Travel Time Matrix 2018.

As the first step in the survey data processing, all IP addresses were anonymised and replaced with identifiers of ten characters consisting of numbers 0–9 and letters of English alphabet (figure 3, section 1). The anonymisation was carried out in such a way that the random identifiers for respondents matched in both *records* and *visitors*, preserving the possibility to associate survey responses with survey visits.

The data processing proper started with loading the open spatial data presented in table 4 and selecting only areas and attribute data relevant to the research (figure 3, section 2). For *CORINE*, this meant selecting only areas marked Level1Eng, Artificial surfaces. *YKR zones*, a dataset that covers the entirety of Finland, was clipped with the spatial dimensions of *postal* with an additional 500 meter buffer. *postal* was processed to only include areas reachable by car from the mainland (figure 17). Islands not reachable by car were approximated visually using Google Maps and were removed from the data. However, some islands in the Helsinki Capital Region are technically accessible with a car from the mainland, but in practice the access is limited. In these cases, deliberation was used. For example, Suomenlinna islands and Korkeasaari were kept in the data. Conversely, some technically car-accessible islands like Staffan in Espoo, and Mustasaari and Seurasaari in Helsinki were removed from the data with the grounds of them containing only private property, or no public parking spaces. By removing the islands unreachable by car, we evade a source of uncertainty that could arise in the data analysis – it would be misleading, for example, to include forested, inaccessible islands in the calculation of artificial surfaces carried out for each postal code area.



(a) Unedited postal code areas for the Helsinki Capital Region.



(b) Postal code areas of the Helsinki Capital Region, with islands unreachable by car removed.

Figure 17. Islands unreachable by car were removed from the postal code area dataset in the Python data processing.

Helsinki Region Travel Time Matrix 2018 and the survey data of this thesis operate in different spatial units. Travel time Matrix 2018 uses the MetropAccess-YKR-grid (*grid*), a spatial dataset based on the Statistics Finland statistical grid with the cell size of 250 x 250 meters. The basic spatial unit of the survey data is the postal code area based on PAAVO open data. Using Python, postal codes were added to each *grid* cell with the logic that the largest area in *postal* (figure 18) assigns the postal code in each *grid* cell. *postal* polygons do not always intersect with the cells of *grid* and because of this some cells were assigned a postal code of 99999 to denote missing data. As a side product of this postal code assignment, *grid* was merged with data which tells how much of a cell was contained in the study area (*postal*) and how large was the largest postal code area which dictated the postal code assignment of the current cell.

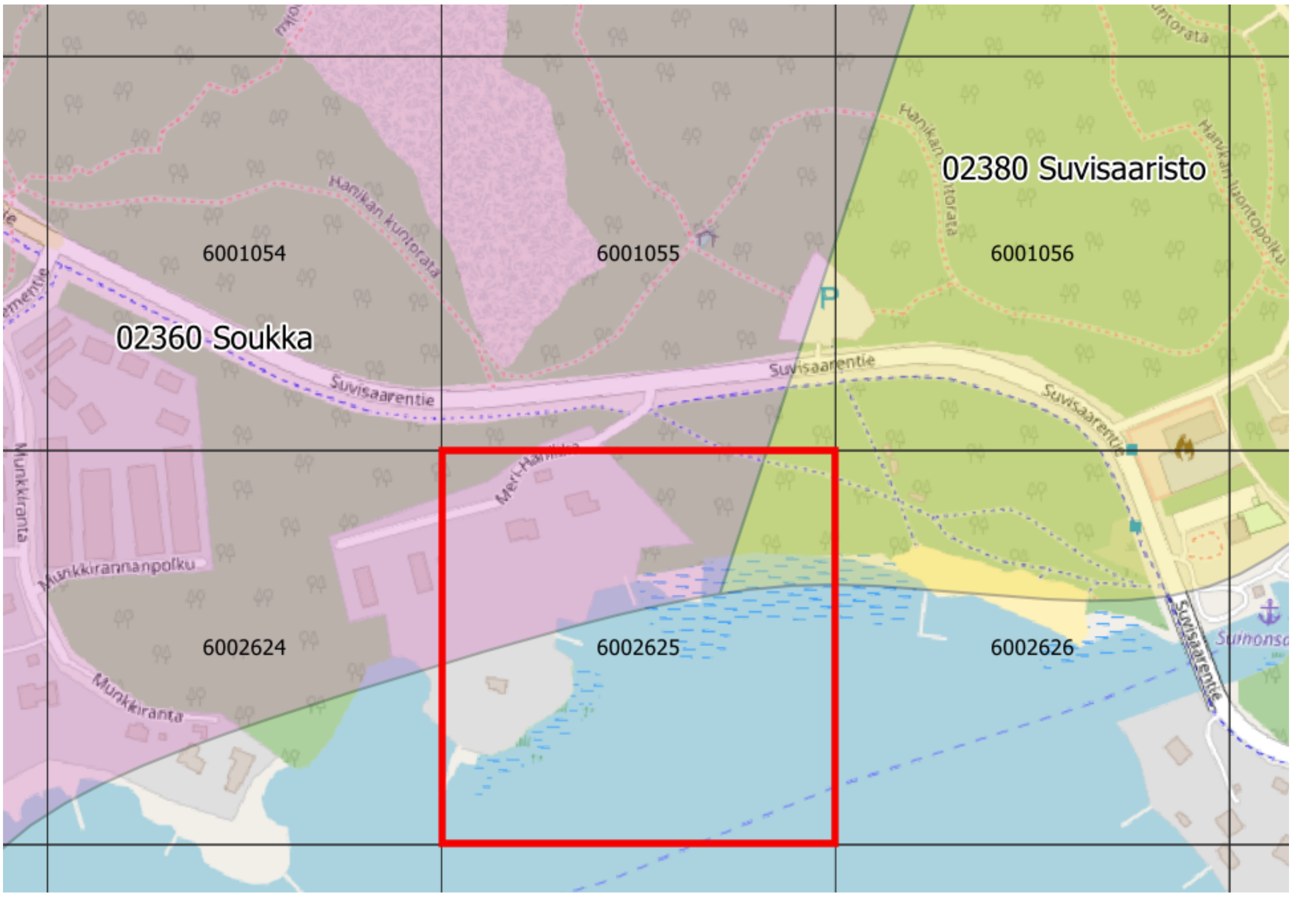


Figure 18. The MetropAccess-YKR-grid cell 6002625 (marked with the red square) is assigned postal code 02360 because in that grid cell, the largest segment of PAAVO open data (coloured warm purple and yellow) belongs in the postal code 02360 Soukka. (OpenStreetMap contributors 2020)

The data processing script created for this thesis contains detailed features to detect patterns in the survey data (figure 3, section 3). To enhance pattern recognition, *records* and *visitors* were purged of known false data, which were namely responses and visits made by me.

The data processing script creates two distinct reports about *records*. Firstly, the data processing script aggregates *records* by IP address code, resulting in an Excel file where one row represents each respondent. It is then possible to review the behaviour of each respondent in detail. In addition to this report, the data processing script writes a text file report about IP address codes which submitted multiple responses from the same postal code area. The text file report also identifies whether the duplicate responses for each postal code area per each IP address code have identical values or if they have changed between responses. These two reports were used to determine what to do about the duplicates and values which appear anomalous.

It was decided that if the parking time or walking time value in a *records* row was 60 minutes or greater, that data row would be deleted. This value is arbitrary. The research assumes that it is highly unlikely that anybody would generally park 60 minutes away from their final destination to which they would then proceed on foot. A hour of searching for parking is plausible in the center of Helsinki but because of its unlikeliness the same 60 minutes limit was utilised in searching for parking. It is not possible to determine why multiple survey responses contain the maximum value for `parktime` and `walktime`, 99, but it can not be ruled out that these data rows are protest votes meant to declare that reliable parking is hard to find in certain parts of the Helsinki Capital Region. When advertising the thesis survey on Facebook, some people took the opportunity to voice their displeasure at the perceivedly difficult parking conditions in the Helsinki Capital Region. In conclusion, even though the Python script has the capability to delete data rows deemed illegal, all of the illegal data in *records* was preserved a more versatile analysis in R.

Next in the survey data processing workflow additional spatial data, variables `ykr_zone` and `artificial`, was added to *postal* (figure 3, section 4). *YKR zones* data was first simplified with the notation presented by the research group at the websites of the zones of urban structure (table 13, Finnish Environment Institute 2013). Then, the percentage shares of each *YKR zones* class in the postal code area were calculated. The zone with the largest percentage value was chosen for each postal code area to finalise the explanatory variable of `ykr_zone`.

Using *CORINE* data, the percentage of artificial surface in each postal code area was calculated. These values were then used to determine class breaks (Jenks natural breaks) for the explanatory variable `artificial` (table 15, figure 20).

Table 13. The logic by which the unedited source data for zones of urban structure was transformed for this thesis.

Original definition	Definition for this thesis
Keskustan jalankulkuvyöhyke	Keskustan jalankulkuvyöhyke
Keskustan reunavyöhyke Keskustan reunavyöhyke/intensiivinen joukkoliikenne Keskustan reunavyöhyke/joukkoliikenne	Keskustan reunavyöhyke
Alakeskuksen jalankulkuvyöhyke Alakeskuksen jalankulkuvyöhyke/intensiivinen joukkoliikenne Alakeskuksen jalankulkuvyöhyke/joukkoliikenne	Alakeskuksen jalankulkuvyöhyke
Intensiivinen joukkoliikennevyöhyke	Intensiivinen joukkoliikennevyöhyke
Joukkoliikennevyöhyke	Joukkoliikennevyöhyke
Autovyöhyke	Autovyöhyke
Areas not in the YKR zones data	novalue

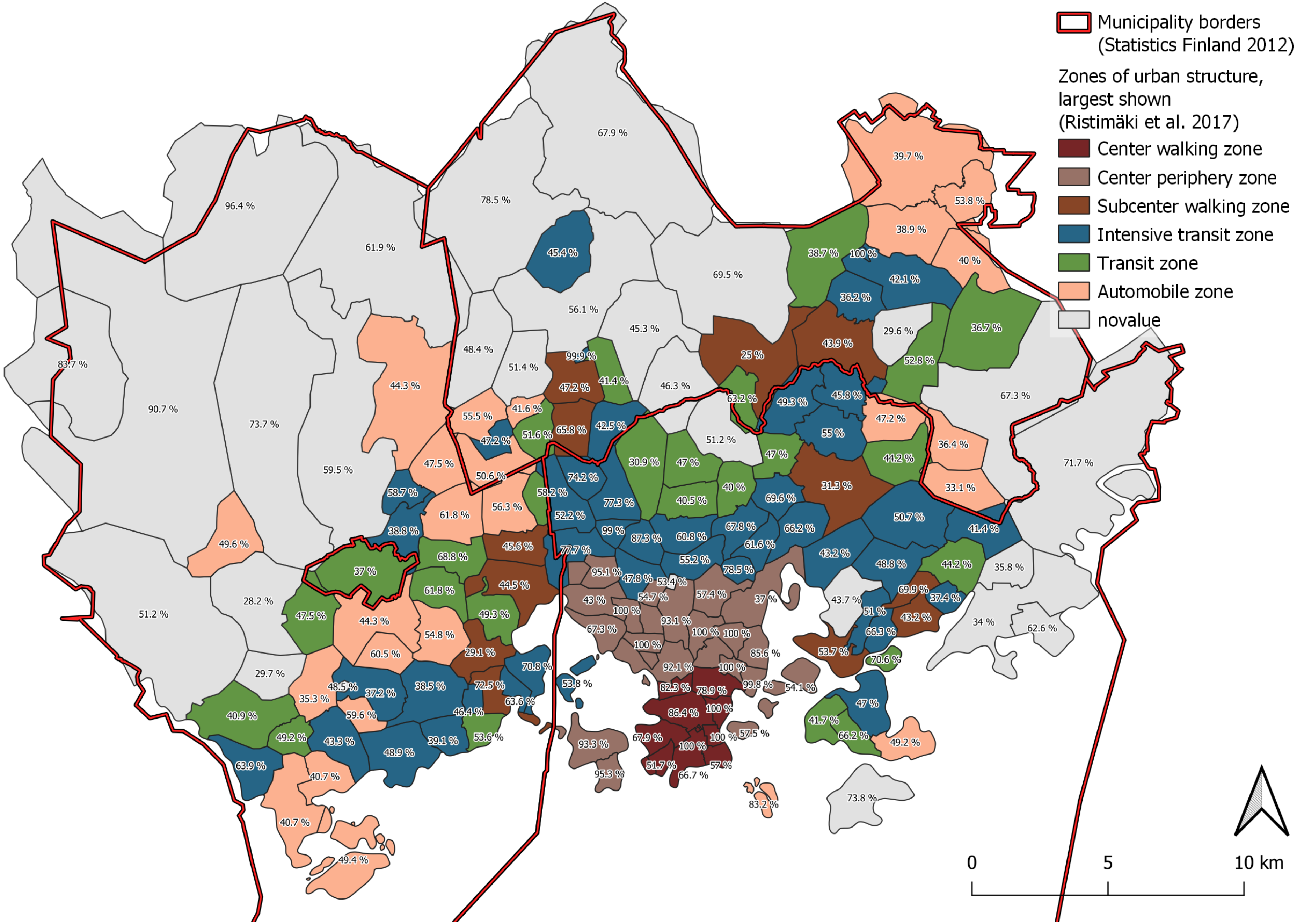


Figure 19. Each postal code area was assigned to belong to a group in the variable `ykr_zone`, explained in table 13, according to which group was largest in area in any given postal code area.

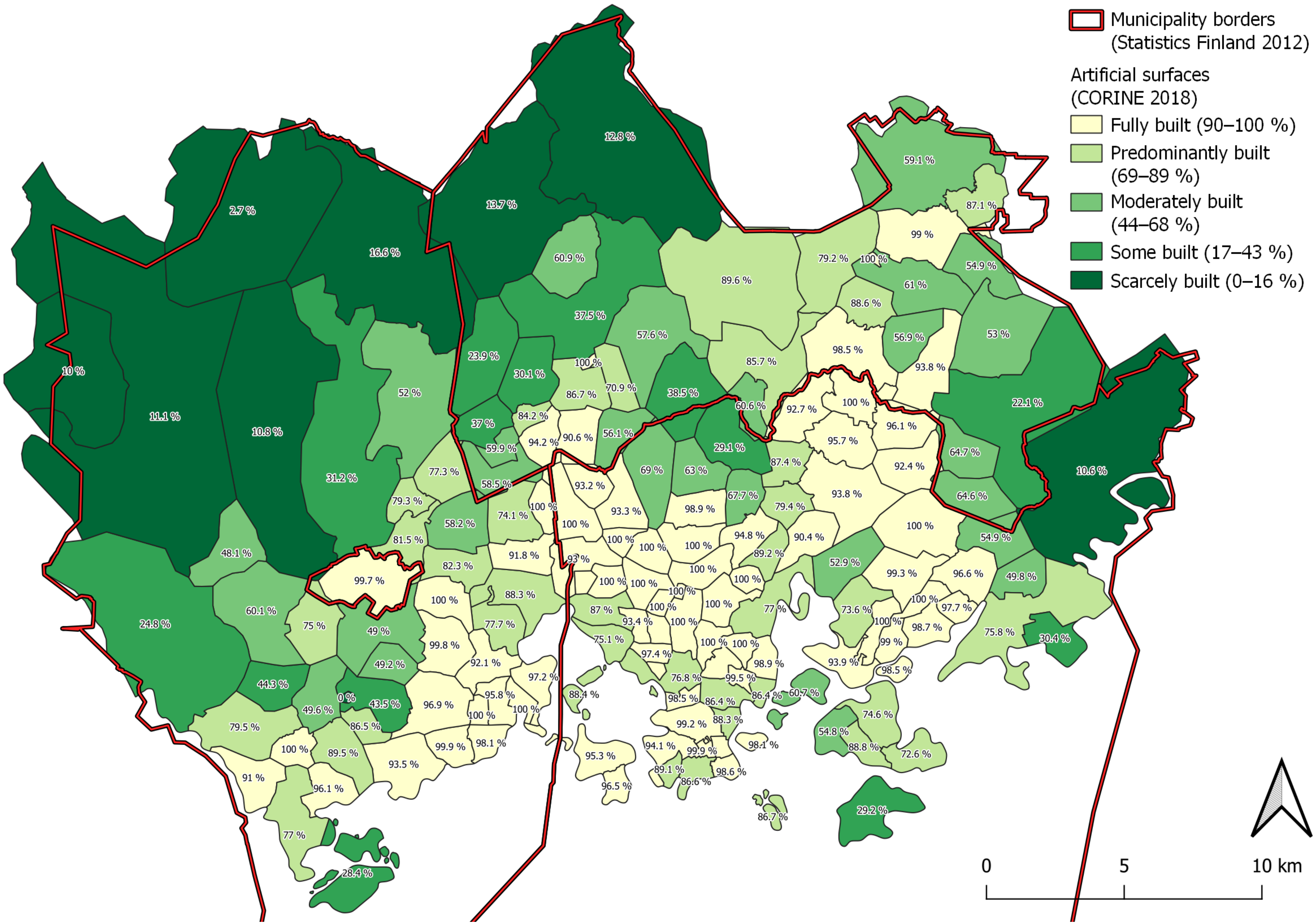


Figure 20. Artificial surfaces are based on CORINE Land Cover 2018.

Table 14. CORINE land cover 2018 data hierarchy under attribute data column Level1Eng, Artificial surfaces.

Level1, Level1Eng	Level2, Level2Eng	Level3, Level3Eng	Level4, Level4Eng
1 Artificial surfaces	11 Urban fabric	111 Continuous urban fabric	1111 Continuous urban fabric
		112 Discontinuous urban fabric	1121 Discontinuous urban fabric
	12 Urban fabric	121 Industrial or commercial units	1211 Commercial units
			1212 Industrial units
	12 Industrial, commercial and transport units	122 Road and rail networks and associated land	1221 Road and rail networks and associated land
		123 Port areas	1231 Port areas
		124 Airports	1241 Airports
	13 Mine, dump and construction sites	131 Mineral extraction sites	1311 Mineral extraction sites
			1312 Open cast mines
		132 Dump sites	1321 Dump sites
		133 Construction sites	1331 Construction sites
	14 Artificial, non-agricultural vegetated areas	141 Green urban areas	1411 Green urban areas
		142 Sport and leisure facilities	1421 Summer cottages
			1422 Sport and leisure areas
			1423 Golf courses
			1424 Race courses

Table 15. Using a custom algorithm, the variable `artificial` was divided to classes using Jenks natural breaks method.

`artificial` value	Description	Amount of postal code areas
< 100 %	Fully built	77
< 89.6 %	Predominantly built	39
< 69.0 %	Moderately built	28
< 44.3 %	Some built	14
< 16.6 %	Scarcely built	9

In the finalising section, *records* was prepared for analysis and visualisation in R (figure 3, section 5). The software library for plotting in R, *ggplot2*, prefers data inputted in long format. To study characteristics of postal code areas in this research, it meant adding repetitive data columns in *records*, where values for CORINE land cover 2018 artificial surfaces, YKR zone and subdivision remained unchanged for all rows in the same postal code area. For artificial surfaces, a custom Jenks natural breaks function with five classes were utilised to find the applicable Jenks breaks class for each postal code area. For *YKR zones*, the most common urban structure type in percentage was selected for each postal code area. In addition, *records* was inserted with municipality subdivision information (figure 21). This was achieved by collecting data from the web sites of the municipalities of the Helsinki Capital Region (Espoon kaupunki 2020, Helsingin kaupunkiympäristön toimiala 2019, Vantaan kaupunki 2019). In these sources, each municipality broke the subdivisions down to city district level, from where it was possible to allot each postal code area with a subdivision. This was for the most part simplistic work, but in some cases the postal code areas and city districts did not align and author's own deliberation was used to help the placement. Some of the most glaring discrepancies between the postal code areas and subdivision boundaries occur in Espoo. In the case of Lippajärvi-Järvenperä, a postal code area north of Kauniainen, the subdivision Vanha-Espoo was chosen because Lippajärvi-Järvenperä as a whole does not fit into the characteristics of Suur-Leppävaara, and at the same time the city districts Lippajärvi and Järvenperä do not fit into the distinctive features of the subdivision Pohjois-Espoo. In the same spirit the postal code area Sepänkylä-Kuurinniitty south of Kauniainen lies troublingly in the area of four subdivisions of Espoo. In the end Vanha-Espoo was chosen as Sepänkylä-Kuurinniitty lies for the most part in its area. Similar complications occurred in Helsinki and Vantaa (the partial placement of Kirkonkylä-Veromäki and Ruskeasanta-Ilola in subdivision of Tikkurila) and using my best judgement, the classification shown in figure 21 was used in the survey results analysis of this thesis.

The source code for the data processing described in this chapter is available at GitHub (`https://github.com/sampoves/Msc-thesis-data-analysis`).

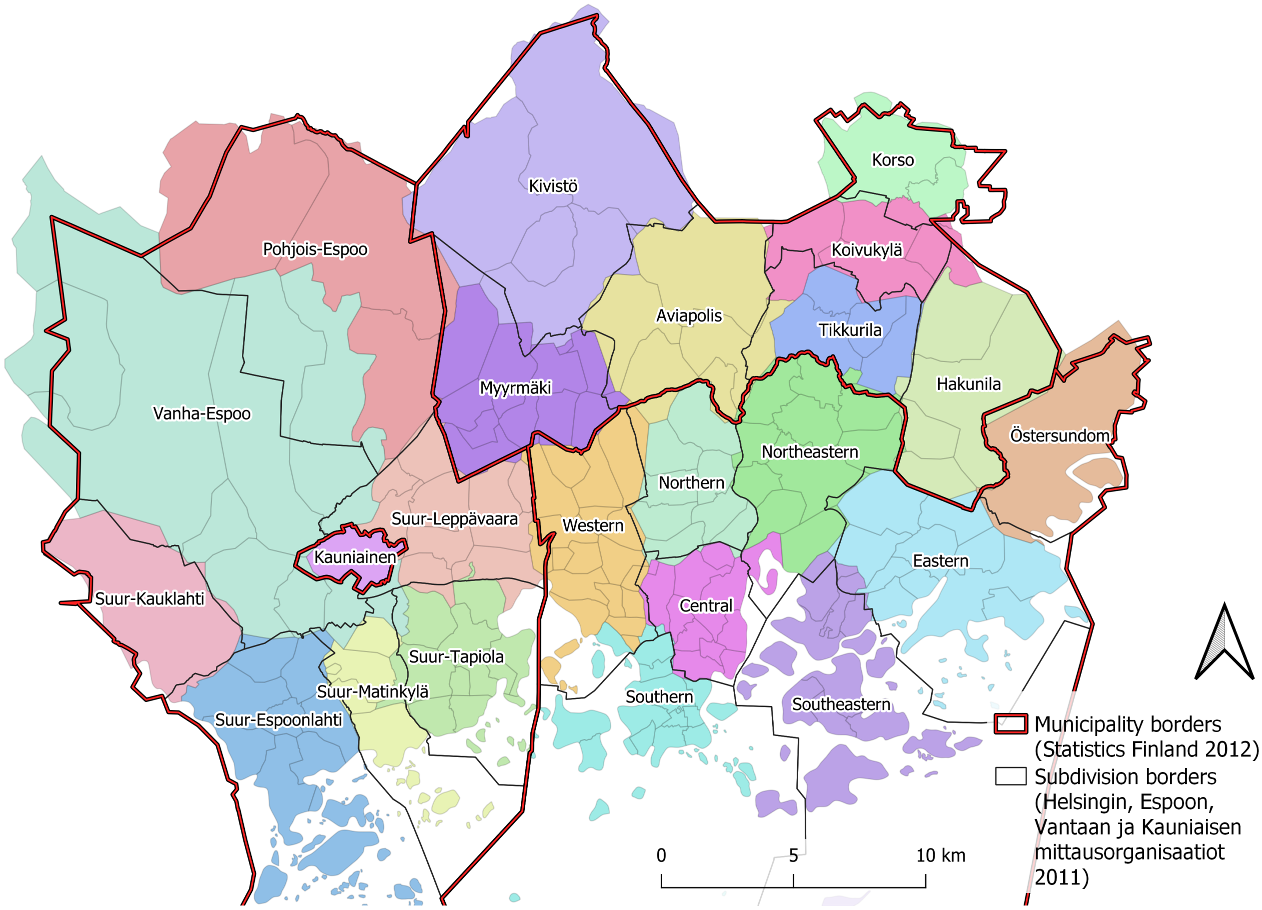


Figure 21. For the purposes of analysis in R, all postal code areas in *postal* were assigned with subdivision information. In this figure, distinct colors depict the postal code areas with the subdivision classification chosen for this thesis.

3.7 Creating applications and conducting analyses

3.7.1 Analysis application

Once the data processing in Python was completed, *records* and *visitors* were carried over to R to utilise its easy to access statistical analysis functionality. For this thesis, this meant namely packages *onewaytests* for ANOVA and Brown-Forsythe test, *plotrix* for standard error, and *moments* for quantiles (table 6). To help study the large datasets, three Shiny applications were written (Shiny is a web application framework software package for R), one for *records* and a second for *visitors*, and a third one to study differences between the thesis survey results and Helsinki Region Travel Time Matrix 2018. Benefits in creating these applications were twofold. Firstly, approaching the survey results from an interactive perspective allowed countless combinations of active and inactive variables – without constant tweaking of code – which would be beneficial for the analysis of *records*. Secondly, programming the applications using Shiny enabled the use of shinyapps.io, a service where one can host Shiny applications on the internet without charge. Combination of these two factors made it effortless to analyse results of the survey in a visual way and at the same time, publish the tools and results to the public, upholding the thesis' mission of openness and transparency.

In the Shiny analysis application for *records*, users can view the survey responses from many different angles (figure 22). Users are given control which variables are active at any moment. Users control the variables through the side panel, with settings taking effect in the main panel. The variables currently viewed are selected through two dropdown menus, Response (continuous) and Explanatory (ordinal). Continuous variables are `parktime` and `walktime` with an integer range 0–99. Available ordinal variables are `likert`, `parkspot`, `timeofday`, `artificial`, `ykr_zone`, and `subdiv` with the values that can not be unequivocally ordered in a sequence in the same way as continuous variables. One variable from each variable group can be selected at the same time. Any and all groups of values in the ordinal variables can be deactivated to better understand the significance of each value group. In addition to the selection of the continuous and ordinal variable, users can deactivate *records* data rows based on their spatial location in municipality subdivisions assigned in subsection 3.6, Processing survey data. Most importantly, the analysis application allows selection of maximum allowed value for `parktime` and `walktime`. The default value for both is set at 59 minutes, as discussed in the subsection 3.6, Processing survey data, but the user is free to choose any value between zero and 99.

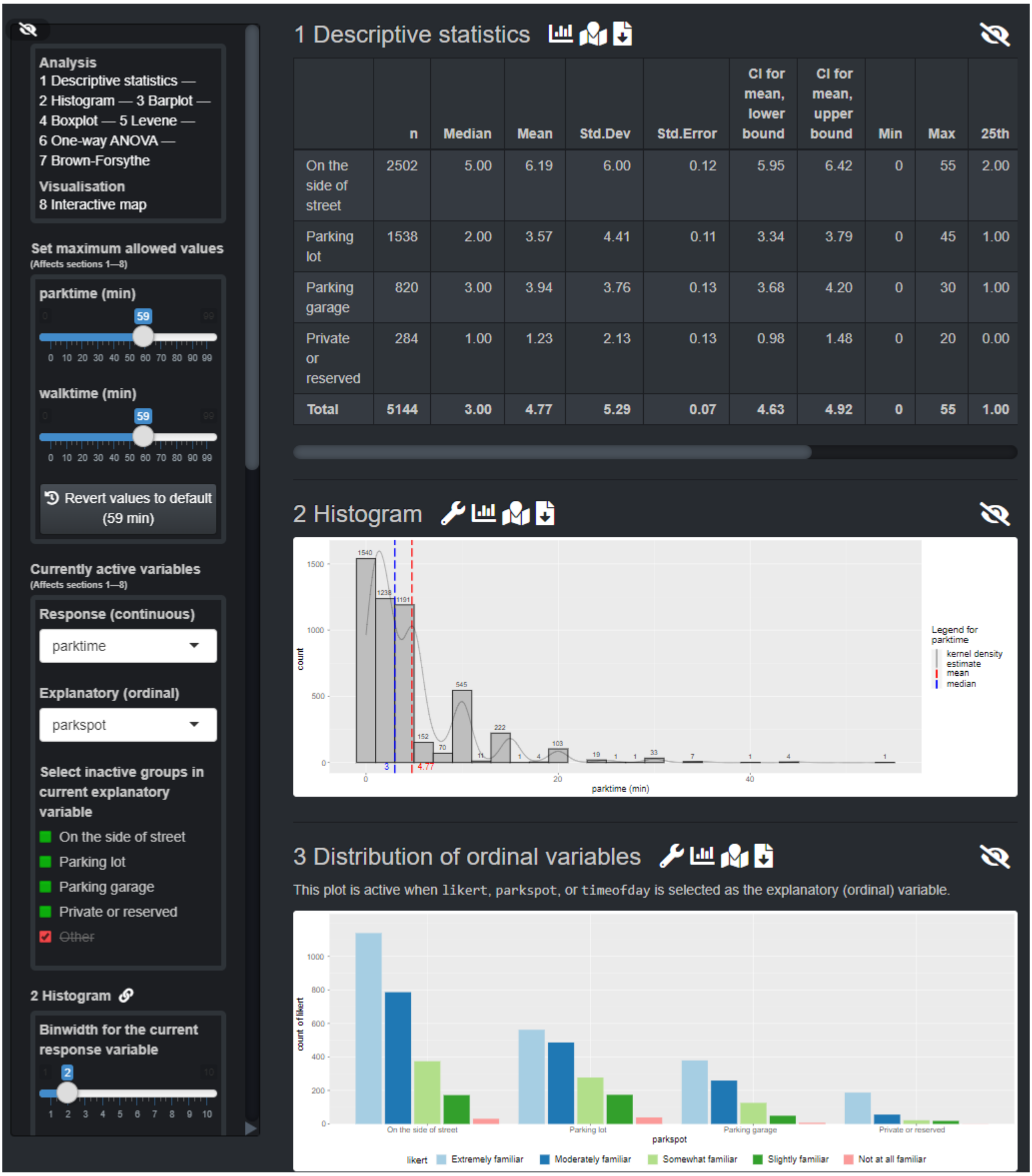


Figure 22. A segment of the shinyapps.io deployment of *records* analysis application. The web application provides a wide array of analysis and visualisation tools for the results of the thesis survey research. The application is available for use at `https://sampoves.shinyapps.io/analysis`.

Table 16. *records* Shiny application features. All features are affected by the maximum permitted `parktime` and `walktime` values, currently active response and explanatory variables and inactive subdivisions. In addition, certain exclusive settings are found in some of the features.

Feature	Type	Outputs	Feature exclusive settings
1 Descriptive statistics	Analysis, table	n, median, mean, standard deviation, standard error, confidence interval for mean, lower bound, confidence interval for mean, min, max, 25th quartile, 75th quartile, skewness, kurtosis	None
2 Histogram	Analysis, chart	Histogram, kernel density estimate, mean, median	Histogram binwidth
3 Distribution of ordinal variables	Analysis, chart	Distribution plot by explanatory variable value group	Explanatory variable for the distribution plot Y axis
4 Boxplot	Analysis, chart	Quartile data	None
5 Test of homogeneity of variances (Levene's test)	Analysis, table	Equality of variances for a variable calculated for the currently active response and explanatory variable	None
6 Analysis of variance (ANOVA)	Analysis, table	Analysis of differences among group means in a sample	None
7 Brown-Forsythe test	Analysis, table	Analysis of equality of group variances	None
8 Interactive map	Visualisation, map	Choropleth map with Jenks breaks classification, descriptive data per postal code area (answer count, mean and median for parktime and walktime, forest amount percentage, largest YKR zone percentage)	- Selection of active municipalities - Jenks breaks parameter column - Amount of Jenks breaks classes - Possibility to visualise the map with boundaries and labels

When the user has selected a continuous and an ordinal variable to compare, they are presented a thorough set of descriptive statistics for the currently active data rows with n, median, mean, standard deviation, standard error, confidence interval for lower and upper bound, minimum and maximum, 25 % and 75 % quantiles, skewness, and kurtosis (table 16). For the continuous variables, a histogram is available to visualise the distribution of `walktime` and `parktime`. Distribution of ordinal variables `likert`, `parkspot`, and `timeofday` can be compared against other ordinal variables in a barplot. To study quartiles, a boxplot is available. Importantly, users can test their selection of variables with the test of homogeneity of variables (Levene's test), analysis of variance (ANOVA), and the Brown-Forsythe test. Lastly, a versatile interactive map of the study area is provided. This map, divided in postal code areas, reveals the survey results in a spatial fashion. The interactive map is affected by the maximum parking time and walking time, selection of an ordinal variable and any inactive subdivisions to provide a flexible view into the details of the data. In addition, this interactive map is controlled by some exclusive settings of its own. The interactive map settings offers six distinct parameters for viewing the study area through Jenks natural breaks classification, alongside with the possibility to select the amount of classes in the map view. Hovering the cursor over the map reveals a tooltip which the application users can use to view mean, median, and percentage data about each postal code area in the Helsinki Capital Region. Tooltips are also available for the barplot of distribution of ordinal variables and the boxplot.

Much additional work was put into the analysis application to make it as clear and easy to use as possible. The application features a number of links to move between the features and the settings, while smooth scrolling and animations help in directing the attention of the user. Each application feature can be switched on and off to make space for exactly the topic the user wants to examine. The analysis application allows downloading all the results, outputting tables into comma separated value files (CSV). Charts and the map are outputted into high resolution images (PNG). The files are intuitively named informing of the used application settings and the date of file download. Attention was given to ensure the usage of the analysis application on mobile phones. To this end, the CSS style sheet of the application detects mobile phone screen sizes and adjusts the application content accordingly. The sidebar tends to block the view of the main panel on mobile screens and for this situation a switch is provided to hide the sidebar at any given time. All graphical elements of the application are in SVG (Scalable Vector Graphics) format which supports effortless zooming without loss of detail.

The source code for the *records* analysis application is available at GitHub (`https://github.com/sampoves/thesis-analysis-shinyapps`). The application may be viewed on shinyapps.io (`https://sampoves.shinyapps.io/analysis`).

3.7.2 Visitors application

In the Shiny application for *visitors*, users can examine events in the timeline of the survey research (figure 23). In this interactive view, cumulative charts are presented for received survey responses and survey page first visits. The charts reveal the effect and importance of advertisement on actual received responses and survey traffic. While not completely verifiable, the significance of different sources of responses can be viewed in the application.

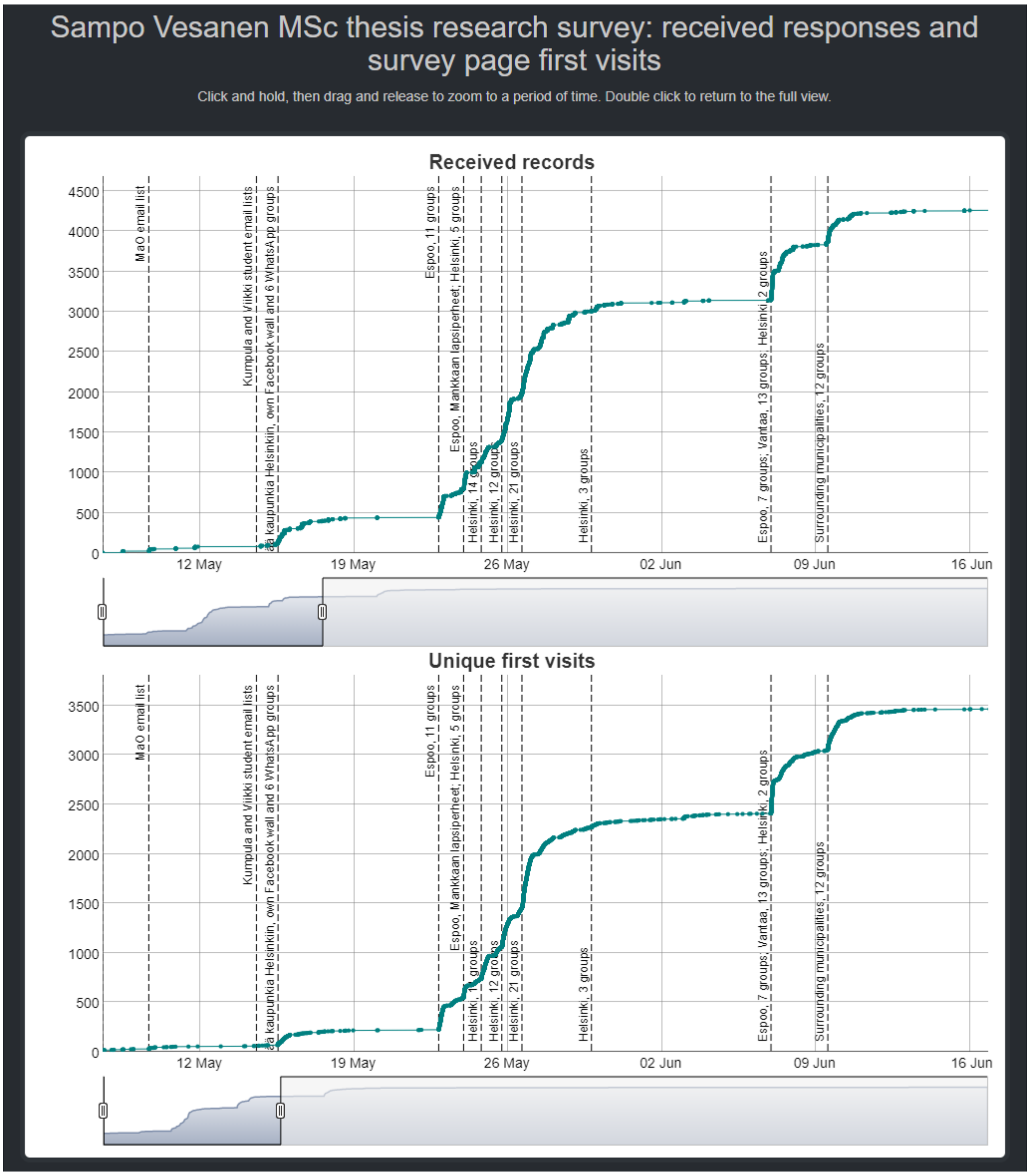


Figure 23. The shinyapps.io deployment of *visitors* analysis application. In this web application users may examine how the amounts of submitted responses and unique first visits to the thesis web survey developed over time. The application is available for use at https://sampoves.shinyapps.io/visitors.

Compared to the other two analysis applications programmed for this thesis, the *visitors* application is relatively simple in its function and features. The user controls the chart view with mouse button presses or dragging the cursor and no additional settings are provided.

The source code for the *visitors* analysis application is available at GitHub (https://github.com/sampoves/thesis-visitors-shinyapps). The application may be viewed on shinyapps.io (https://sampoves.shinyapps.io/visitors).

3.7.3 Travel time comparison application

Despite potential for extensive analysis, the applications described in previous chapters do not provide means to study the third research question of this thesis:

III What is the significance of the parking process to the overall travel time?

To answer this research question, an application to compare travel time datasets was programmed (figure 24). In this application, the user can view a variety of descriptive values calculated from Helsinki Region Travel Time Matrix 2018, the thesis survey data, and a dataset created by comparing the two datasets. The user is given control a set of features, such as a selection of the travel times origin postal area code, the parameter to visualise on the map, and the amount of classes to show on the map. The map view can be customised with a number of additional spatial data for the purpose of visualisation, such as regional boundaries and physical features (inland water, main roads), and options for the labelling of postal code areas. The application supports downloading any map view in high resolution png format image.

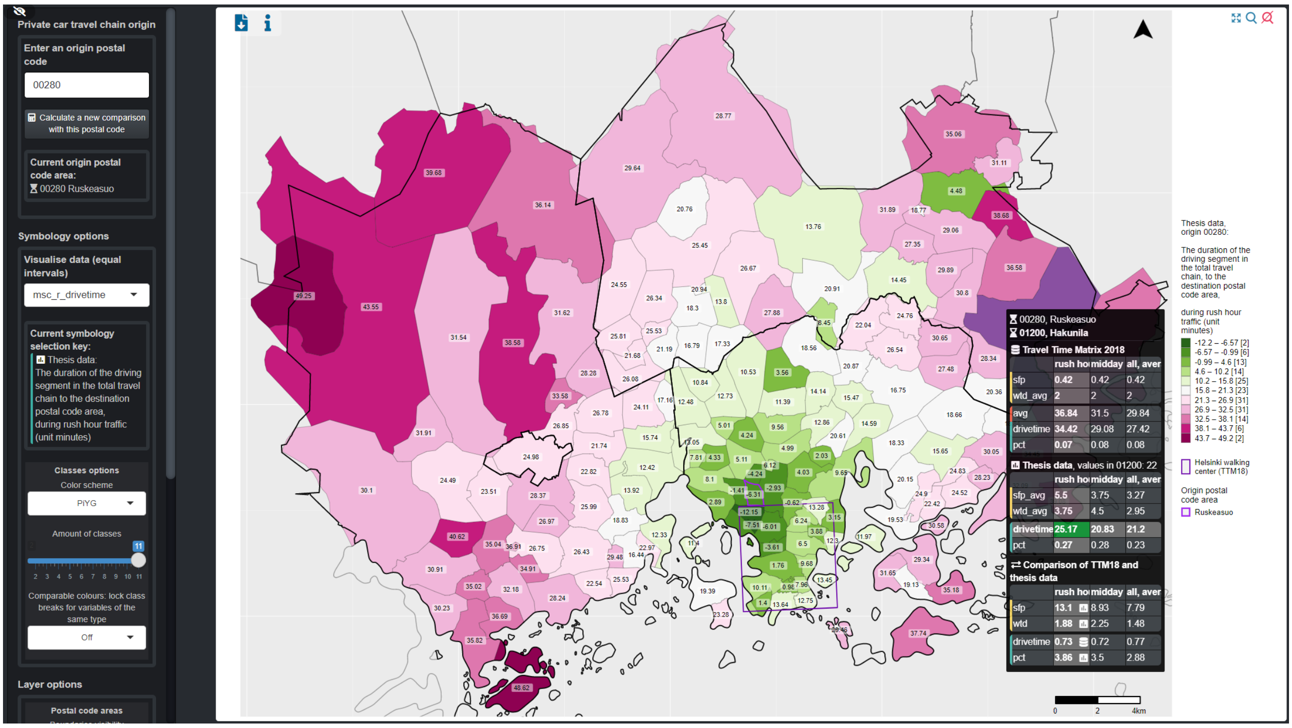


Figure 24. Helsinki Region Travel Time Matrix 2018 and thesis survey data comparison application's shinyapps.io deployment. The cursor hovers over 01200 Hakunila with the data tooltip active. The application is available for use at `https://sampoves.shinyapps.io/comparison`.

It was decided that the basic spatial unit for the comparison application would be the postal code areas as the thesis survey results exist in that resolution. This decision necessitated extensive processing of the *Travel Time Matrix* data. Firstly, the application needed to be able to recalculate the map view as quickly as possible. Secondly, the original *Travel Time Matrix* dataset is unwieldy to be used in its original format in a web application (data stored in uncompressed txt files, data scope much too detailed for the application). Thirdly, the hosting service shinyapps.io places technical limitations on the resource intensity of the application. For these three main reasons, the library *fst* (table 6) was first used to convert the *Travel Time Matrix* private car columns into the data format used by the library (table 17), and then using the dataset *grid* preprocessed in Python to aggregate all *Travel Time Matrix* grid cell values to the postal code area level and writing the results using the optimised *fst* format (table 18). For data completeness, *Travel Time Matrix* searching for parking (0.42 minutes) and walking to destination (2.0–2.5 minutes) data was added to these aggregated *Travel Time Matrix* files. This aggregation method for the *Travel Time Matrix* data drastically reduces unnecessary real-time processing, minimises disk space needed, and keeps application memory footprint in manageable figures for the deployment of the application to the internet. The other main dataset used in the comparison application, the thesis survey data, is aggregated each time the application initialises, as the complete survey results dataset is miniscule in size compared to the *Travel Time Matrix*.

Table 17. An excerpt of the data content of the *Travel Time Matrix* converted to fst format for further processing (table 18). Original file 5785xxx/travel_times_to_ 5785640.txt.

	from_id	to_id	car_r_t	car_m_t	car_sl_t
10	5787549	5785640	22	21	16
11	5787550	5785640	22	21	16
12	5789447	5785640	10	9	8
13	5789448	5785640	10	9	8
14	5789449	5785640	11	10	9

Table 18. An excerpt of the data content of the *Travel Time Matrix* aggregated to postal code area level for the use of the comparison application. The origin postal code area of the shown data table is 00100 Helsinki Keskusta – Etu-Töölö.

	zipcode	from_zip	ttm_r_avg	ttm_m_avg	ttm_sl_avg	ttm_wtd	ttm_sfp
5	00150	00100	14.89	13.24	9.48	2.33	0.42
6	00160	00100	15.48	13.97	9.77	2.50	0.42
7	00170	00100	14.41	13.10	9.09	2.50	0.42
8	00180	00100	12.77	11.34	8.40	2.50	0.42
9	00190	00100	24.27	22.31	17.04	2.00	0.42

The survey data gathered for this thesis does not contain any additional data about the driving segment of travel chains in the Helsinki Capital Region. To gain this information, all *grid* cells were associated with a postal code area to enable the aggregation of the *Travel Time Matrix* data by that variable. Then, total travel times were extracted from every postal code area to all other postal code areas using the newly aggregated *Travel Time Matrix* data, and substracting those values with the length of the *Travel Time Matrix* parking process (2.42–2.92 minutes). These driving time segment values were then added up with the thesis survey `parktime` and `walktime` data, creating fully comparable travel chains from the realistic durations of the *Travel Time Matrix* data and the newly collected parking survey data. In the travel time comparison application the user can access all calculated values by hovering the cursor over a postal code area (figure 25). The calculation formulas and abbreviated column names are further explained in table 19.

With the help of this travel time comparison application it is effortless to get an overall picture of private car parking time characteristics in the Helsinki Capital Region and most importantly, to answer the third research question of this thesis, view the share of the driving segment and parking process segment in aggregated travel chains from a postal code area to another. Moreover, the application advances the communication of the results of this thesis in a tangible way while being transparent of its inner workings.

The source code for the *comparison* analysis application is available at GitHub (`https://github.com/sampoves/thesis-comparison-shinyapps`). The application may be viewed on shinyapps.io (`https://sampoves.shinyapps.io/comparison`).

Table 19. Travel time comparison application's tooltip (figure 25) content legend. All values are per postal code area.

	Column name in app	Column name in data	Unit	Description	Formula
timeofday	r	r	N/A	Rush hour traffic (09:00–11.00, 15.00–17.00)	–
	m	m	N/A	Midday traffic (09.00–15.00)	–
	all	all	N/A	An average of all available data. For *TTM*, these are *Rush hour traffic*, *Midday traffic*, and *Route following speed limits without any additional impedances.* For thesis survey data, these are the values of the survey question `timeofday`: *Weekday, rush hour*, *Weekday, other than rush hour*, *Weekend*, and *Can't specify, no usual time* (table 8).	$\frac{value_1+value_2+...+value_n}{n}$
Travel Time Matrix 2018	sfp	ttm_sfp	min	Time consumed in searching for parking. In *TTM*, this is 0.42 minutes for all YKR IDs in the entirety of Helsinki Capital Region (Toivonen et al. 2014).	–
	wtd_avg	ttm_wtd_avg	min	An averaged value of walking time from one's parked private car to the final destination of the travel chain. In *TTM*, this is 2.0 minutes for all *grid* cells in the entirety of Helsinki Capital Region, except in a square defined over the center of Helsinki, where the value is 2.5 minutes for all *grid* cells (Toivonen et al. 2014).	–
	avg	ttm_x_avg	min	A mean duration of the complete travel chain with private car from origin postal code area to the destination postal code area.	$\frac{car\_x\_t_1+car\_x\_t_2+...+car\_x\_t_n}{n}$, where x is r, m, or all. $car\_$ represents unchanged *TTM* data columns.
	drivetime	ttm_x_drivetime	min	The length of the driving segment of the mean duration of the complete travel chain from origin postal code area to the destination postal code area without searching for parking (using the *TTM* value) or walking to the final destination of the travel chain (*TTM* value).	$ttm\_x\_avg - ttm\_sfp - ttm\_wtd\_avg$
	pct	ttm_x_pct	%	How much does searching for parking and walking from one's parked car to the final destination of the travel chain constitute of the mean duration of the complete travel chain?	$\frac{ttm\_sfp+ttm\_wtd\_avg}{ttm\_x\_avg}$
Thesis data	sfp_avg	thesis_x_sfp	min	Time consumed, on average, in searching for parking in a postal code area, according to the thesis survey respondents.	$\frac{parktime_1+parktime_2+...+parktime_n}{n}$, while postal code value is constant.
	wtd_avg	thesis_x_wtd	min	Average walking time from one's parked private car to the final destination in a postal code area, according to the thesis survey respondents.	$\frac{walktime_1+walktime_2+...+walktime_n}{n}$, while postal code value is constant.
	drivetime	thesis_x_drivetime	min	The length of the driving segment of the mean duration of the complete travel chain (*TTM* data) from the origin postal code area to the destination postal code area, without searching for parking (thesis survey mean) or walking to destination (thesis survey mean).	$ttm\_x\_drivetime - thesis\_x\_sfp - thesis\_x\_wtd$, where x is r, m, or all.
	pct	thesis_x_pct	%	How much do the thesis mean values for searching for parking and walking from one's parked car to the final destination constitute of the mean duration of the complete travel chain?	$\frac{thesis\_x\_sfp+thesis\_x\_wtd}{ttm\_x\_drivetime}$
Compare TTM and thesis	sfp	compare_x_sfp	%	Compare *TTM* and thesis survey values for searching for parking.	$\frac{thesis\_x\_sfp}{ttm\_sfp}$, where x is r, m, or all.
	wtd	compare_x_wtd	%	Compare *TTM* and thesis survey values for the duration to walk from one's parked car to the final destination of the travel chain.	$\frac{thesis\_x\_wtd}{ttm\_wtd\_avg}$
	drivetime	compare_x_drivetime	%	Compare the driving time segment of the mean duration of the complete travel chain in TTM and thesis data.	$\frac{thesis\_x\_drivetime}{ttm\_x\_drivetime}$
	pct	compare_x_pct	%	Compare the percentual value of the significance of searching for parking and walking to one's final destination of the mean duration of the complete travel chain in *TTM* and thesis data.	$\frac{thesis\_x\_pct}{ttm\_x\_pct}$

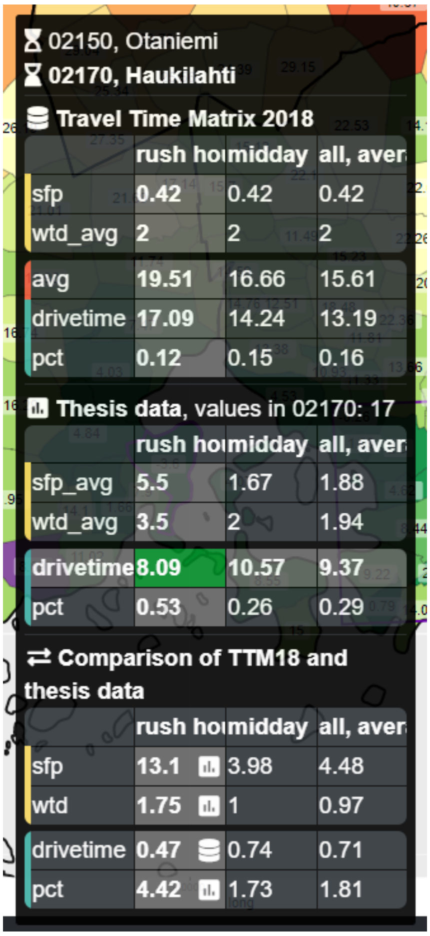


Figure 25. Close-up of a tooltip for a travel chain from 02150 Otaniemi to 02170 Haukilahti. The cell coloured green informs the user that currently visualised on map is thesis data, the travel chain without searching for parking or walking to one's destination, in rush hour traffic.

4 Results

4.1 Survey results overview

In this chapter, the thesis research survey results are presented. Within the selected criteria (`parktime < 60` and `walktime < 60`, see subsection 3.6, Processing survey data), the survey received a total of 5579 visits from 4320 unique IP addresses. 848 unique IP addresses visited the survey more than one time and a total of 1060 unique IP addresses responded to the survey. 24.5 % of all visitors submitted at least one data row. On average one respondent submitted 4.9 data rows.

The survey received in total 5183 data rows. All postal code areas were represented in the survey results, but the data row count histogram was heavily skewed to the right, with the first quartile being eight data rows, second (median) 17 data rows and third 42 data rows (table 20, figures 26, 27). Most respondents reported short parking times below ten minutes, but the histograms do not smoothly lessen in values from the right to left, as respondents have preferred to report round figures such as five, ten, or fifteen minutes. There were five postal code areas with more than one hundred data rows and 55 postal code areas with less than ten data rows. In Helsinki, the answers strongly clustered around the center of Helsinki, with other centers of activity being Herttoniemi and Itäkeskus-Marjaniemi in Helsinki, Tapiola-Otaniemi and Leppävaara in Espoo, and Tikkurila-Vantaanportti in Vantaa.

Table 20. Amount of data rows received per municipality in the Helsinki Capital Region.

Municipality	Data rows total	Most data rows in municipality	Data rows mean in municipality	Data rows median in municipality
Helsinki	3777	271 (00100 Helsinki Keskusta - Etu-Töölö)	45.0	34.5
Espoo	637	84 (02600 Etelä-Leppävaara)	17.7	9
Vantaa	746	91 (01510 Kirkonkylä-Veromäki)	16.2	8
Kauniainen	23	23 (02700 Kauniainen)	23	23
All	5183	271 (00100 Helsinki Keskusta - Etu-Töölö)	31.0	17

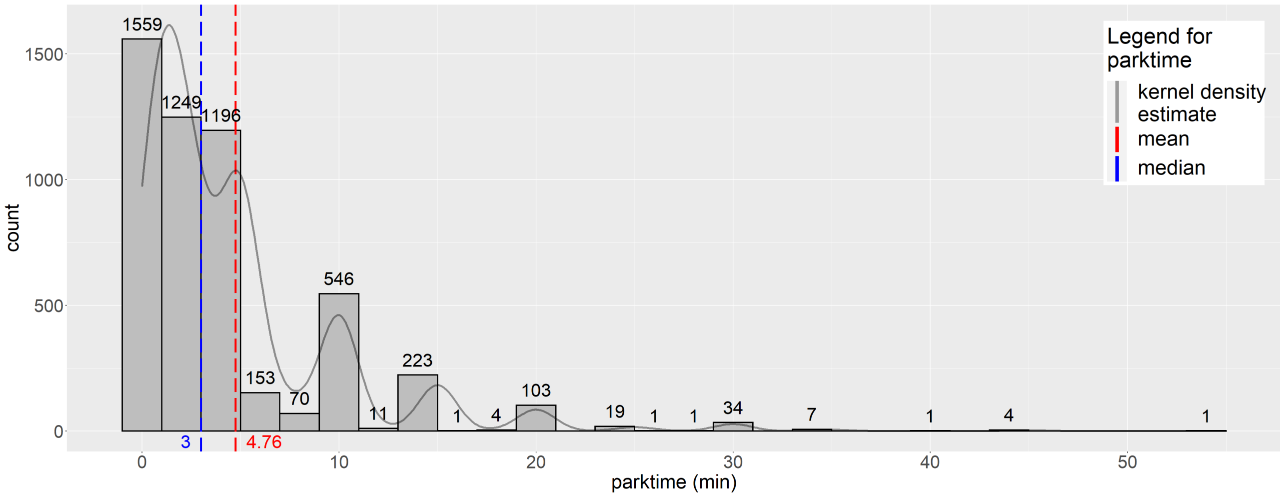


Figure 26. All thesis survey `parktime` values (< 60) shown on histogram.

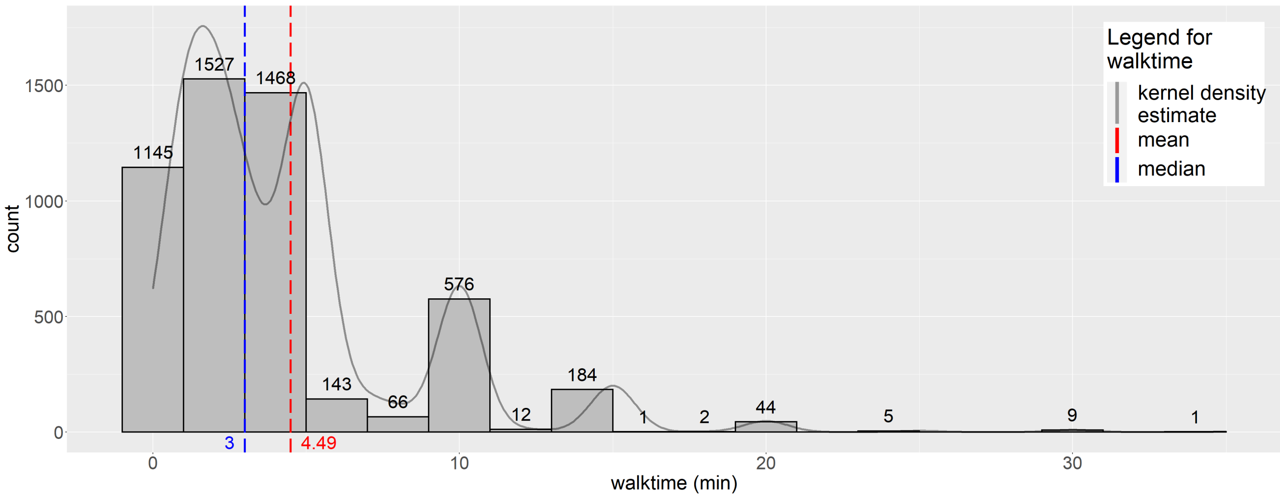


Figure 27. All thesis survey `walktime` values (< 60) shown on histogram.

On a closer look to the municipalities, finer details become apparent (figure 28). For example, in Helsinki, a wedge-like area of survey activity in the direction of southwest-northeast is visible. Starting out from the west, this area spans from Lauttasaari to the center of Helsinki and moving on all the way east to Malmi. Many of the areas which could be roughly characterised as residential areas were left with little activity. Furthermore, in the survey instructions respondents were requested to refrain from including parking activity in private property, as it was assumed in survey design phase that these areas would provide near to instantaneous parking, potentially distorting the data and obfuscating the objectives set by the thesis research questions. The lightness of activity in residential areas corresponds with the made request.

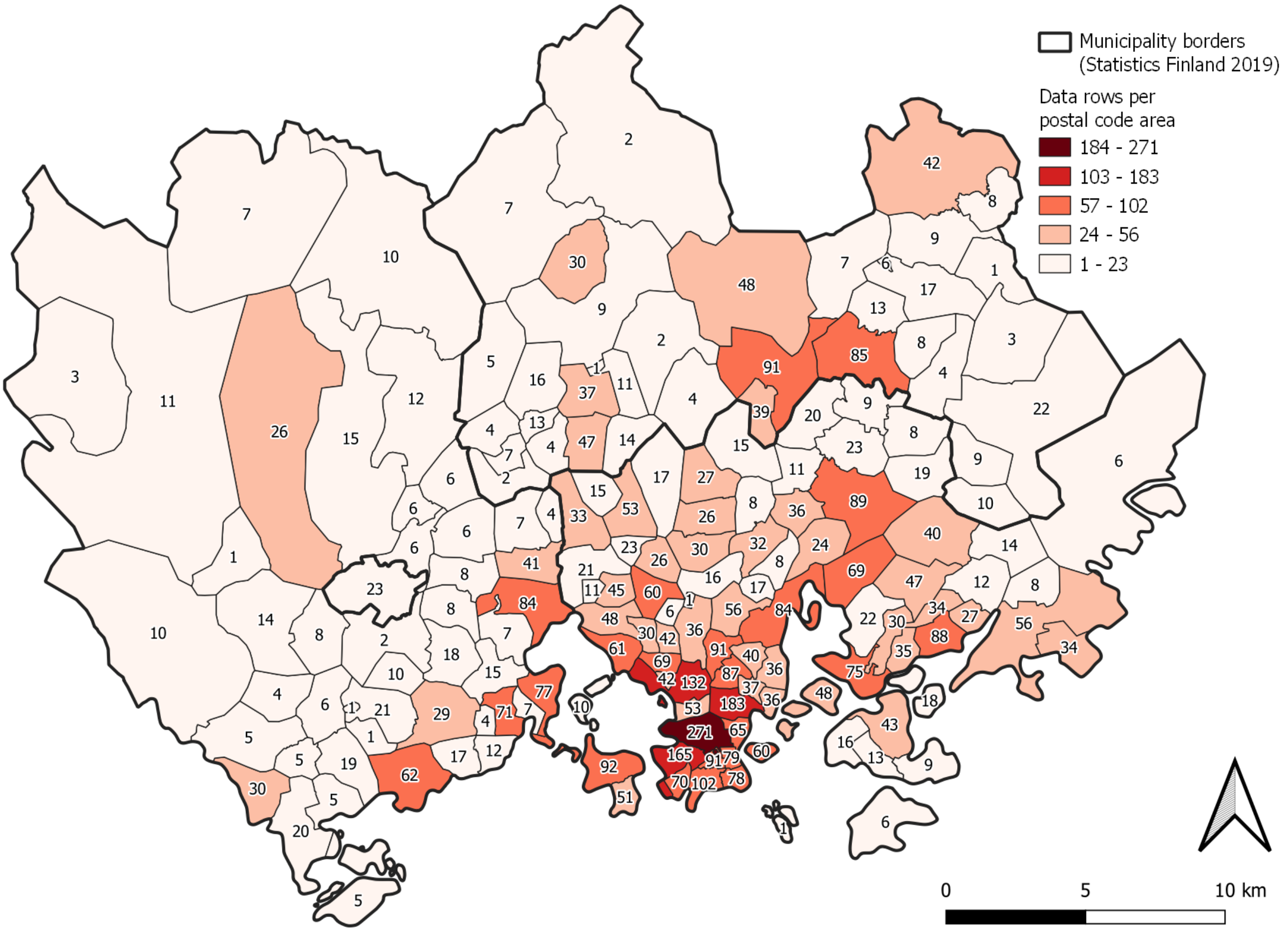


Figure 28. This figure illustrates the responses received in the thesis survey per postal code area (n=167). Classes are in natural breaks (Jenks). Municipality borders are based on *postal* data. There are slight differences to the actual municipality boundaries. View these differences in figure 4.

In the finest resolution available, the postal code areas, long `parktime` values closely follow areas with most survey activity (figures 29, 30). The longest `parktime` values were encountered in the center of Helsinki, where the mean value for 00120 Punavuori was 10.6 minutes (median 10.0 minutes, 91 data rows) and 00290 Meilahden sairaala-alue 9.4 minutes (5.0 min, 42 rows) (see appendices I and II for locations of these areas). Long parking times over five minutes were recorded in all over the center area, but also in 00570 Kulosaari (5.3 min, 5.0 min, 48 rows) and 00590 Kaitalahti (6.5 min, 3.5 min, 16 rows). In Espoo, the longest `parktime` values were found in 02230 Matinkylä (5.1 min, 5.0 min, 62 rows), 02100 Tapiola (4.6 min, 3.0 min, 71 rows), and in 02320 Espoonlahti (4.3 min, 3.0 min, 30 rows). In Vantaa, it took the longest to find a parking spot in 01300 Tikkurila (6.4 min, 5.0 min, 85 rows). According to the survey results, it was relatively hard to find a parking spot in 01700 Kivistö (5.7 min, 4.0 min, 30 rows), too.

In the case of this survey dataset, it is important to not lose sight of median, as mean is susceptible to outliers, of which there are many present. One such situation may be viewed in 01750 Keimola, where the mean `parktime` is 5.9 minutes, and median reads at 1.0 minute. In Keimola's situation, one respondent entered a `parktime` value of 25 minutes, severely skewing the total sample of seven values. It may be argued that when detecting areas of long duration of searching for parking, median is the better measure to identify areas of interest.

The descriptive `walktime` values follow the same municipal order as those of `parktime`: On average, in Helsinki it took 4.8 minutes (median 4.0 minutes) to walk from one's parked car to the final destination of the journey (figure 31, 32). In Vantaa, this process was 4.0 minutes (3.0 min), while Espoo had mean parking time of 3.9 minutes (2.0 min) and Kauniainen 2.2 minutes (2.0 min). Of the entire study area, Espoo's 02780 Kauklahti stood out with a mean walking time of 6.3 minutes (5.5 min) to one's destination. It is notable that this subdivision received 10 answers, ranking second to the last before Helsinki's 00890 Östersundom's total of 6 answers.

When viewed through postal code areas, `walktime` shows the longest durations to walk from one's car to the final destination in Helsinki with the top belonging to 00100 Helsinki Keskusta – Etu-Töölö (mean 7.4 minutes, median 5.0 minutes, 271 data rows). Most of the central Helsinki did not fall far behind with most values ranging from five to seven minutes. Outside of the center of Helsinki, 00570 Kulosaari (6.7 min, 5.0 min, 48 rows), 00590 Kaitalahti (6.3 min, 5.0 min, 16 rows) and 00690 Tuomarinkylä-Torpparinmäki (5.3 min, 3.0 min, 15 rows) saw long `walktime` values within the boundaries of Helsinki. Looking outward from the capital, the `walktime` values in Espoo were mostly lower than those in Helsinki. The longest recorded durations in Espoo were in 02100 Tapiola (5.4 min, 5.0 min, 71 rows), 02780 Kauklahti (6.3 min, 5.5 min, 10 rows), and 02820 Nupuri-Nuuksio (7.0 min, 5.0 min, 7 rows). Vantaa's longest `walktime` values were found in 01530 Veromiehenkylä (8.0 min, 5.5 min, 48 rows), 01300 Tikkurila (6.3 min, 5.0 min, 85 rows), and 01700 Kivistö (5.6 min, 5.0 min, 30 rows).

It is difficult to try and determine the causes behind these long `walktime` values, but it may be worth noting that many of the postal code areas with top values contain popular sightseeing locations, such as the Haltiala domestic animal farm in 00690 Tuomarinkylä-Torpparinmäki and the national park of Nuuksio in 02820 Nupuri-Nuuksio. The postal code area of 01530 Veromiehenkylä is almost entirely in the use of Helsinki-Vantaa Airport. It quickly becomes apparent that recreational trips to Nuuksio National Park may nudge the Espoo's `walktime` values upward, while in Vantaa, the Helsinki-Vantaa Airport walking seems to be a similar factor. A summarising feature about `walktime` is that areas of long walking times from one's car to the final destination are not as apparently clustered as those of `parktime` are.

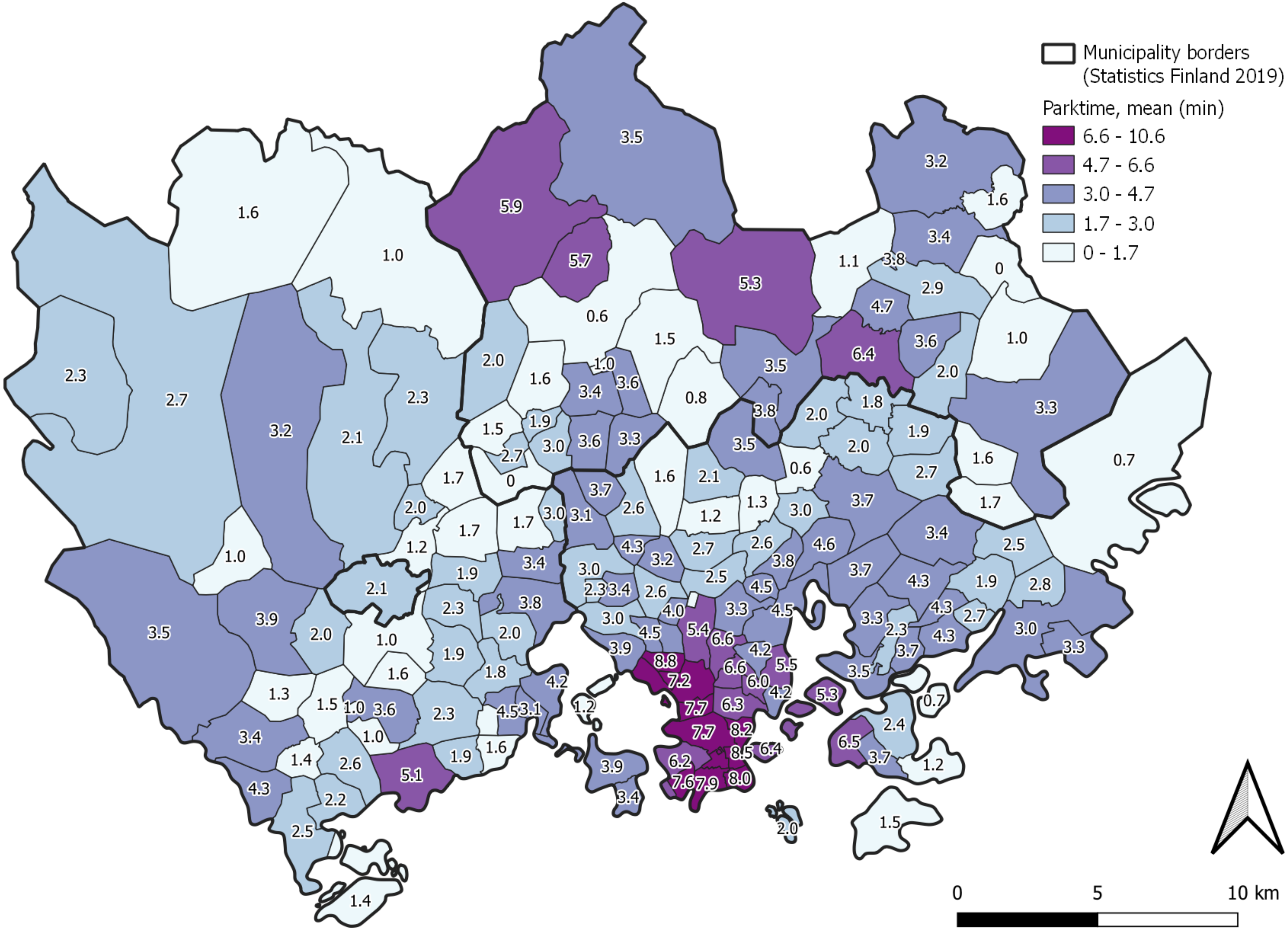


Figure 29. The mean duration (minutes) of searching for parking and parking one's car in each postal code area.

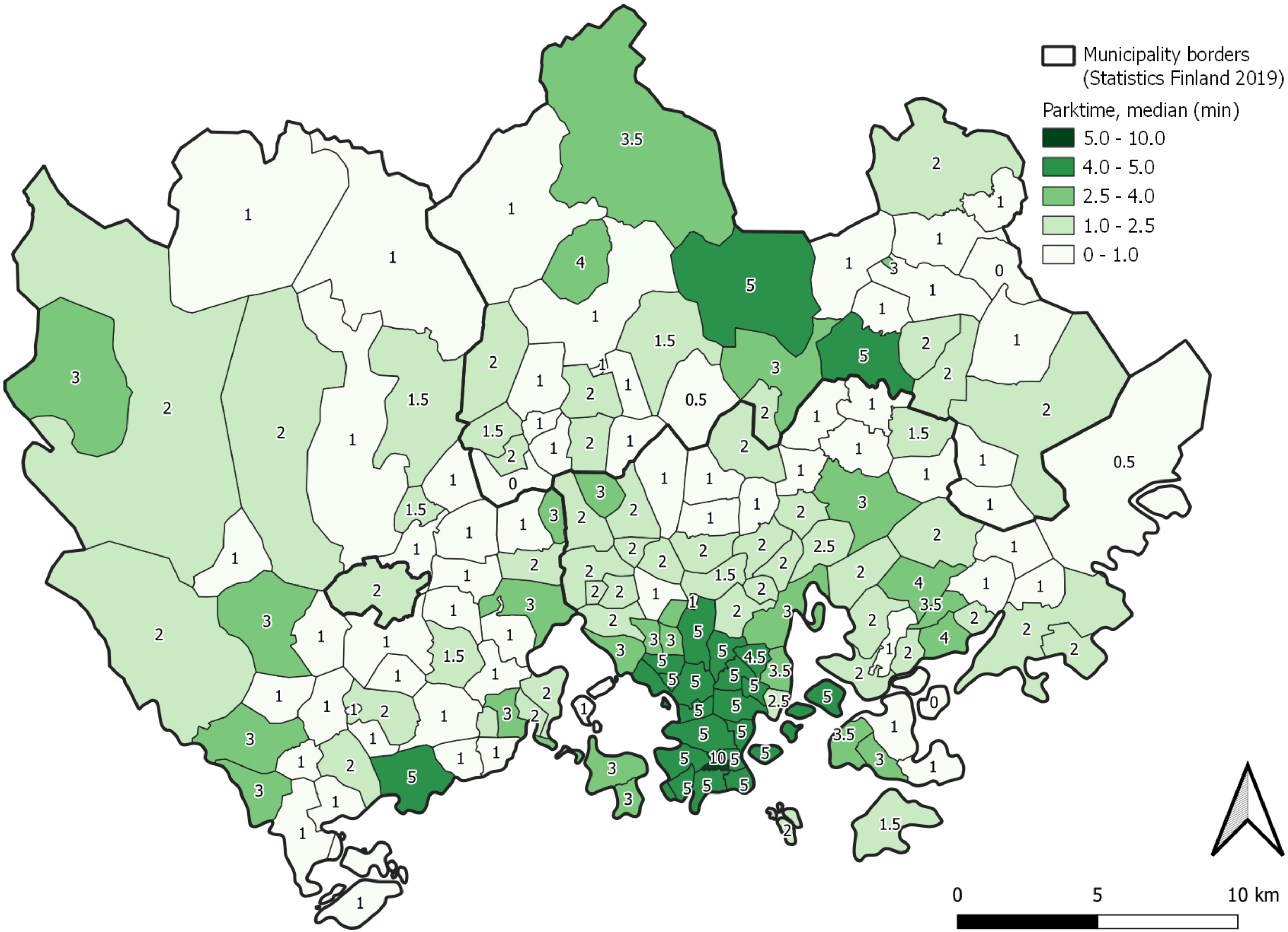


Figure 30. The median duration (minutes) of searching for parking and parking one's car in each postal code area.

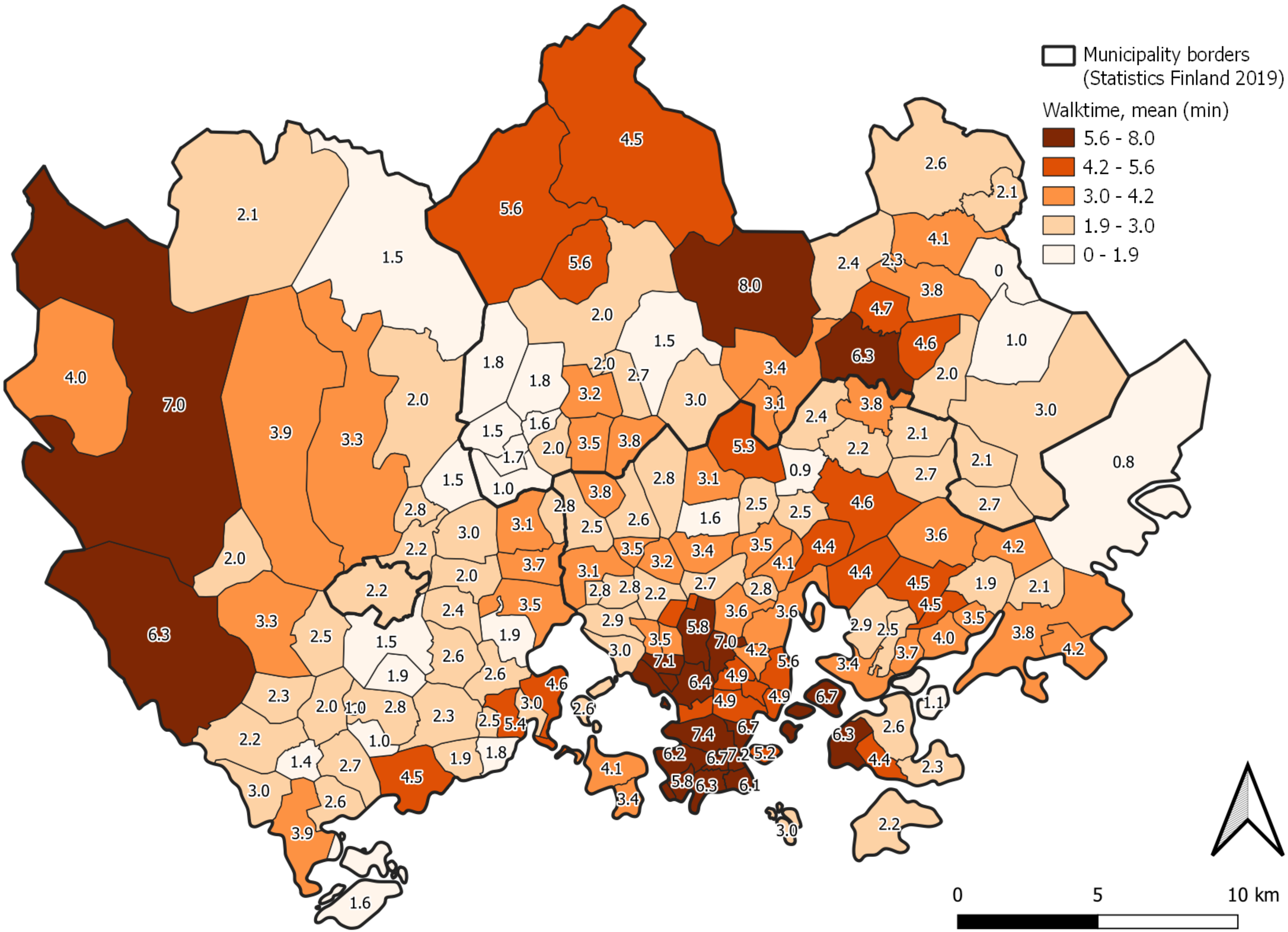


Figure 31. The mean duration (minutes) of walking from one's parked car to the final destination in each postal code area.

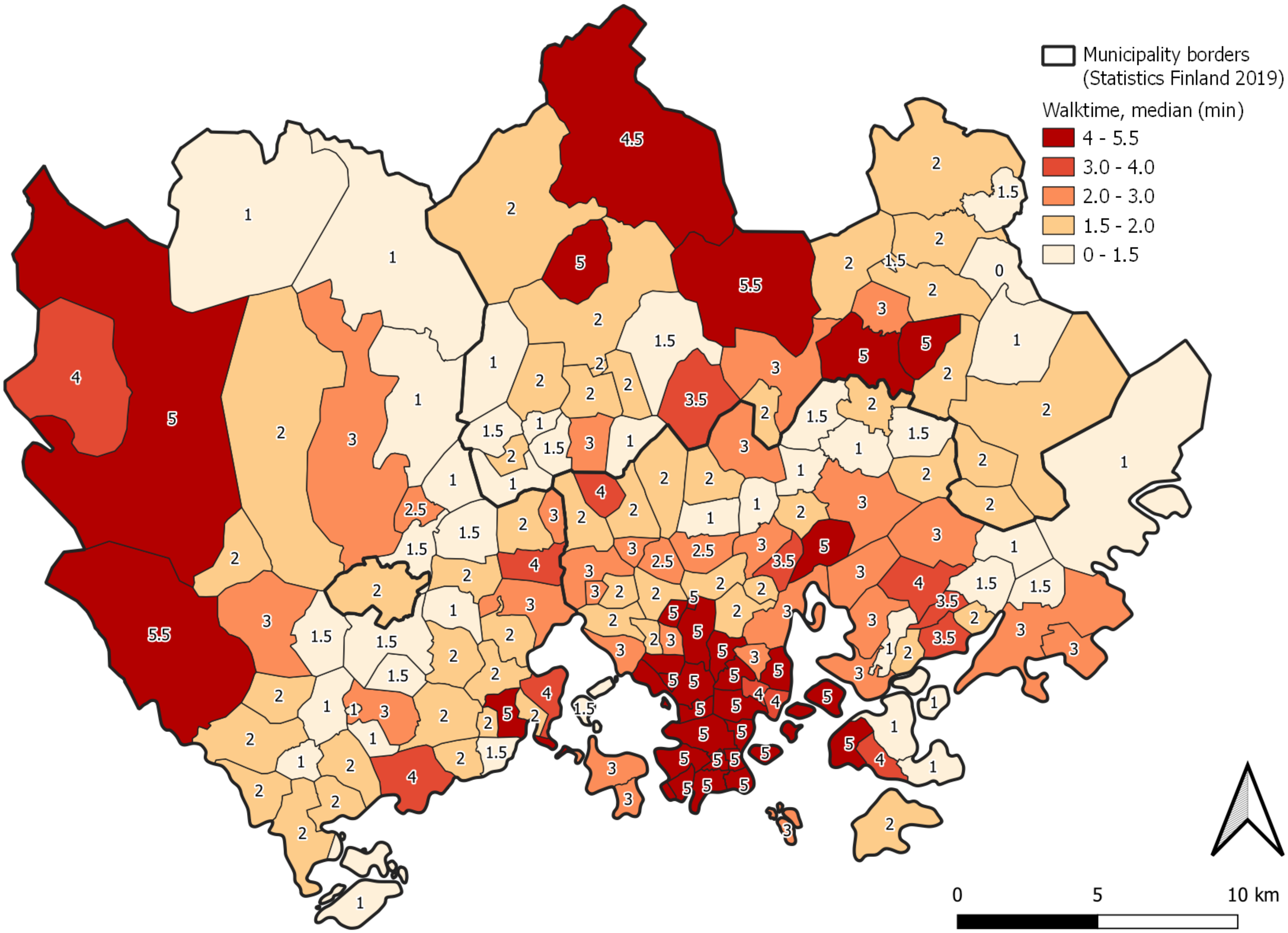


Figure 32. The median duration (minutes) of walking from one's parked car to the final destination in each postal code area.

4.2 Explanatory data analysis

The thesis survey data reveals that there are spatial differences between municipalities and regions of the Helsinki Capital Region (table 21) in the durations to find a parking spot (`parktime`), and walking from one's parked car to the final destination (`walktime`). This is shown by the one-way Analysis of Variance test (ANOVA) that for `parktime` and `walktime` there are statistically significant differences ($p < 0.05$) between the 23 groups (municipality subdivisions, figure 21). In the vast majority of subdivision groups, the group sizes were sufficiently large for ANOVA analysis to be highly significant ($p < 0.001$). An exception to this is the ANOVA test for Espoo's subdivisions using `parktime`. This test finishes with a less significant $p = 0.015$.

In this study, I consider the normality assumption of ANOVA satisfied on the grounds of the central limit theorem. According to central limit theorem, with sample sizes large enough, the mean of independent samples drawn from a distribution of any shape will tend toward a normal distribution (Kwak and Kim 2017).

The spatial differences between subdivisions were wide-ranging, with a 5.2 minutes mean (median 4.0 minutes) `parktime` in Helsinki, 3.8 minutes in Vantaa (2.0 min), 3.2 minutes in Espoo (2.0 min) and lastly, 2.1 minutes (2.0 min) in Kauniainen. Durations to find a parking spot varied inside municipalities; in Espoo, in the subdivision of Pohjois-Espoo, mean `parktime` was 1.7 minutes (1.0 min) while the same value for Suur-Matinkylä was 4.3 minutes (3.0 min). From all the subdivisions in the study area, the subdivision representing the center of Helsinki, Helsinki Southern, had the the longest mean `parktime`, 7.3 minutes (5.0 min). Kauniainen ranked as fourth with a `parktime` values 2.1 minutes mean (2.0 min).

Viewing `walktime` through subdivisions, longest `walktime` was found from Espoo's Suur-Kauklahti (mean 6.3 min, median 5.5 min). In Helsinki, the Southern subdivision's durations were the second longest (mean 6.3 min, median 5.0 min) with Vantaa's top values reaching 5.8 minutes mean and 5.0 median in Tikkurila. Kauniainen's `walktime` values were more moderate with 2.2 minutes mean and 2.0 minutes median.

When comparing specific subdivisions, we can observe finer details in the survey dataset. For example, comparing `parktime` in Espoo's Suur-Tapiola and Vantaa's Aviapolis gives no statistical significance with ANOVA ($F = 2.412$, $p = 0.121$). However, a test with Suur-Tapiola and Helsinki's Southern subdivision is statistically significant ($F = 88.272$, $p < 0.001$, '***'). It is interesting, that an ANOVA `parktime` comparison of Espoo's Suur-Leppävaara and Helsinki's Northeastern subdivisions – both important subcenters of their respective cities – produces no statistical significance ($F = 0.036$, $p = 0.850$).

Differences of Espoo's Vanha-Espoo and Helsinki's Östersundom subdivisions viewed with `walktime` gives a faint statistical significance with ANOVA ($F = 3.807$, $p = 0.054$, '.'). Testing areas with contrasting features, Vanha-Espoo and Vantaa's Tikkurila proved statistically significant ($F = 8.258$, $p = 0.004$, '**'). It is interesting that important city centers receive different results from the ANOVA test. For example, differences in `walktime` are statistically significant ($F = 36.168$, $p \leq 0.001$, '***') between Vantaa's Myyrmäki and Tikkurila subdivisions. `walktime` differences of Espoo's Suur-Matinkylä and Suur-Leppävaara are not ($F = 2.277$, $p = 0.132$). The same case stands for Helsinki's Southeastern and Western subdivisions of which differences were not identified as statistically significant ($F = 0.091$, $p = 0.762$). However, varying degrees of significance is found for the same subdivision comparison pairs when using `parktime` as the explanatory variable: Myyrmäki–Tikkurila achieves high statistical significance ($F = 23.299$, $p \leq 0.001$, '***'), while Suur-Matinkylä–Suur-Leppävaara ($F = 7.296$, $p = 0.007$, '**'), and Southeastern–Western ($F = 7.218$, $p = 0.007$, '**') get moderate significance.

Table 21. Parking times and walking times descriptive statistics displayed by municipalities and subdivisions (the explanatory variable `subdiv`). The unit of median, mean, and standard deviation is minutes. The F value and p value presented are calculated in One-way Analysis of Variance test (ANOVA). P value significance codes: '***' $p \leq 0.001$, '**' $p \leq 0.01$, '*' $p \leq 0.05$, '.' $p \leq 0.1$, 'ns' $p \leq 1$.

			parktime					walktime				
		n	Median	Mean	Std.dev	Std.err	F value, p value	Median	Mean	Std.dev	Std.err	F value, p value
Espoo	Pohjois-Espoo	29	1	1.69	2.12	0.39		1	1.86	1.55	0.29	
	Suur-Espoonlahti	99	2	2.88	3.27	0.33		2	2.83	2.67	0.27	
	Suur-Kauklahti	10	2	3.50	3.69	1.17		5.5	6.30	4.81	1.52	
	Suur-Leppävaara	176	2	3.12	2.94	0.22		3	3.27	2.41	0.18	
	Suur-Matinkylä	95	3	4.28	4.05	0.42		3	3.76	2.81	0.29	
	Suur-Tapiola	257	2	3.33	3.94	0.25		2	3.84	3.41	0.21	
	Vanha-Espoo	80	2	2.81	4.00	0.45		3	3.89	3.81	0.43	
	Total	746	2	3.23	3.63	0.13	2.646, 0.015 (*)	2	3.52	3.09	0.11	4.647, < 0.001 (***)
Helsinki	Central	704	5	5.54	5.72	0.22		5	4.91	3.92	0.15	
	Eastern	360	2	3.61	3.41	0.18		3	3.91	3.51	0.18	
	Northeastern	308	2	3.19	3.83	0.22		3	3.63	3.47	0.20	
	Northern	162	1	2.38	2.73	0.21		2	3.16	3.21	0.25	
	Southeastern	315	2	3.42	3.72	0.21		2	3.70	3.79	0.21	
	Southern	1310	5	7.26	6.47	0.18		5	6.23	4.56	0.13	
	Western	612	2	4.28	5.04	0.20		3	3.63	3.15	0.13	
	Östersundom	6	0.5	0.67	0.82	0.33		1	0.83	0.75	0.31	
	Total	3777	4	5.24	5.60	0.09	53.823, < 0.001 (***)	4	4.78	4.10	0.07	47.497, < 0.001 (***)
Kauniainen	Kauniainen	23	2	2.13	1.60	0.33	—	2	2.22	1.28	0.27	—
Vantaa	Aviapolis	184	3	3.93	4.09	0.30		3	4.51	4.27	0.31	
	Hakunila	44	1.5	2.41	2.89	0.44		2	2.59	2.47	0.37	
	Kivistö	48	1	4.69	6.37	0.92		3	4.88	4.99	0.72	
	Koivukylä	40	1	2.80	3.74	0.59		2	3.33	3.69	0.58	
	Korso	50	2	2.92	4.43	0.63		2	2.50	1.59	0.23	
	Myyrmäki	161	2	2.98	4.13	0.33		2	2.83	3.08	0.24	
	Tikkurila	110	5	5.84	5.60	0.53		5	5.85	5.15	0.49	
	Total	637	2	3.82	4.65	0.18	6.218, < 0.001 (***)	3	3.98	4.11	0.16	9.565, < 0.001 (***)
All	**Total**	5183	3	4.76	5.29	0.07	27.123, < 0.001 (***)	3	4.49	3.99	0.06	23.767, < 0.001 (***)

The municipalities of Helsinki Capital Region show varying results when `parktime` and `walktime` were viewed against the thesis survey variable `timeofday`, the time of day for parking one's car (table 22). Highest values for each choice were found in Helsinki, where `parktime` mean was highest for *Weekday, rush hour* (mean 5.7 min, median 5.0 min). Interestingly, none of the other municipalities had *Weekday, rush hour* as the longest choice. In Espoo, the choice *Can't specify, no usual time* was the longest (3.8 min, 2.0 min), while in Vantaa the choice *Weekday, other than rush hour* took the top position (4.2 min, 2.0 min). In Kauniainen, survey participants reported the longest `parktime` values during the weekend (3.0 min, 3.0 min).

Furthermore, Helsinki also had the longest `walktime` values when viewed against `timeofday`. In the capital, it took the longest to walk from one's car to the final destination on weekend (mean 5.1 min, median 5.0 min). For Espoo, survey participants again reported the highest `walktime` value for the choice *Can't specify, no usual time* (4.0 min, 3.0 min). In Vantaa, one had to walk the longest from the car to the final destination during weekday's rush hour (4.7 min, 3.0 min), while in Kauniainen, weekend private car users spent the longest time walking from their car to their destination (2.6 min, 2.0 min).

The one-way ANOVA test yielded varying results when comparing choices of `timeofday` inside the municipalities of Helsinki Capital Region. Highly significant differences between the time of the the day of parking and the response variables were only detected in Helsinki, where the significant results of $F = 5.913$, $p \leq 0.001$ (`parktime`), and $F = 6.808$, $p \leq 0.001$ (`walktime`) were reached. The corresponding test for Espoo produced a weaker statistical significance with `parktime` ($F = 2.857$, $p = 0.036$, '*') and `walktime` ($F = 3.121$, $p = 0.02$, '*'). The ANOVA test results for Kauniainen were entirely non-significant while Vantaa's ANOVA test results produced a non-significant result for `parktime` and a weak statistical significance for `walktime` ($F = 6.372$, $p = 0.067$, '.').

Groups were excluded from the variable `timeofday` in a test to see if it would enhance statistical significance of differences between the rest of the groups. This proved unsuccessful. For example, statistically significant differences could not be found for `timeofday` groups when concentrating on Vantaa and `parktime`. Each group was successively excluded from the test and additionally hypothetically different times of day were compared to each other (*Weekday, rush hour–Weekend*).

Table 22. Parking times and walking times descriptive statistics with explanatory variable `timeofday`. The unit of median, mean, and standard deviation is minutes. The F value and p value presented are calculated in One-way Analysis of Variance test (ANOVA). P value significance codes: '***' $p \leq 0.001$, '**' $p \leq 0.01$, '*' $p \leq 0.05$, '.' $p \leq 0.1$, 'ns' $p \leq 1$.

			parktime					walktime				
		n	Median	Mean	Std.dev	Std.err	F value, p value	Median	Mean	Std.dev	Std.err	F value, p value
Espoo	Weekday, rush hour	174	2	3.26	3.91	0.30		2	3.60	3.18	0.24	
	Weekday, other than rush hour	227	2	2.79	3.00	0.20		2	3.05	2.59	0.17	
	Weekend	155	2	3.11	2.81	0.23		3	3.57	2.88	0.23	
	Can't specify, no usual time	190	2	3.82	4.48	0.33		3	3.96	3.62	0.26	
	Total	746	2	3.23	3.63	0.13	2.857, 0.036 (*)	2	3.52	3.09	0.11	3.121, 0.025 (*)
Helsinki	Weekday, rush hour	900	5	5.71	6.38	0.21		5	4.99	4.29	0.14	
	Weekday, other than rush hour	1360	4	5.41	5.42	0.15		4	4.83	3.97	0.11	
	Weekend	698	3.5	4.94	4.76	0.18		5	5.06	4.28	0.16	
	Can't specify, no usual time	819	3	4.68	5.58	0.19		3	4.23	3.90	0.14	
	Total	3777	4	5.24	5.60	0.09	5.913, < 0.001 (***)	4	4.78	4.10	0.07	6.808, < 0.001 (***)
Kauniainen	Weekday, rush hour	5	1	1.80	1.79	0.80		2	2.40	1.67	0.75	
	Weekday, other than rush hour	8	2	2.50	1.85	0.65		2	2.38	1.19	0.42	
	Weekend	5	3	3.00	1.22	0.55		2	2.60	1.52	0.68	
	Can't specify, no usual time	5	1	1.00	0.71	0.32		1	1.40	0.55	0.24	
	Total	23	2	2.13	1.60	0.33	1.669, 0.207 (*ns*)	2	2.22	1.28	0.27	0.893, 0.463 (*ns*)
Vantaa	Weekday, rush hour	152	2	3.84	4.95	0.40		3	4.71	5.32	0.43	
	Weekday, other than rush hour	188	2	4.25	5.39	0.39		3	3.75	3.41	0.25	
	Weekend	141	2	3.65	3.44	0.29		3	3.97	3.94	0.33	
	Can't specify, no usual time	156	2	3.45	4.32	0.35		2	3.54	3.58	0.29	
	Total	637	2	3.82	4.65	0.18	0.929, < 0.426 (*ns*)	3	3.98	4.11	0.16	2.399, < 0.067 (.)
All	**Total**	5183	3	4.76	5.29	0.07	5.801, < 0.001 (***)	3	4.49	3.99	0.06	6.372, < 0.001 (***)

The thesis survey data showed marked differences between parking place types in the study area (table 23). Viewing `parktime` and `walktime` through `parkspot` reveals that in all study area municipalities, excluding Kauniainen, parking on the side of the street took the most time. In Helsinki, street parking parking took a mean 6.3 minutes (5.0 min median) while in Vantaa, the corresponding value was 5.8 minutes (4.0 min). In Espoo, street parking was slightly shorter with a mean of 4.1 minutes (3.0 min). In Kauniainen, street parking took a mean duration of 2.33 minutes (1.0 min), with parking in a parking lot narrowly surpassing street parking with a mean 2.35 minutes (2.0 min). In all study area municipalities, parking in parking garages took more time than parking on parking lots. For Helsinki, these values were overall highest with a small margin, 4.0 minutes to 3.9 minutes mean (3.0–2.0 min) for *Parking garage* and *Parking lot*, respectively. Corresponding values in Vantaa were 4.0–3.5 minutes mean (3.0–2.0 min) and in Espoo 3.6 minutes compared to 2.9 minutes mean (3.0–2.0 min). In Kauniainen, no parking garage responses were recorded, with the value *Parking lot* receiving a mean duration of 2.3 minutes (2.0 min).

Walking to one's destination from the parked car also was the longest when participants had parked on the side of the street, again excepting Kauniainen. `walktime` was highest in Vantaa, with a mean duration of 5.15 minutes (4.5 min median). Helsinki's values came in second at 5.12 minutes mean (5.0 min). Espoo and Kauniainen's figures were at 4.0 (3.0 min) and 2.3 minutes mean (1.0 min), respectively. As with `parktime`, the hierarchy of values being greater when parking in a parking garage compared to a parking lot was also demonstrated in `walktime`. The longest durations were recorded in Helsinki with 5.0 to 4.3 minutes mean (5.0–3.0 min) for *Parking garage* and *Parking lot*, respectively. In Vantaa, the values were 4.8–3.6 minutes mean (4.0–2.0 min) and in Espoo 3.9–3.3 minutes mean (3.0–2.0 min).

The thesis survey data shows that `parktime` and `walktime` in private parking lots or non-personal reserved parking spots was under two minutes mean ($\leq$ 1.0 min median) in all municipalities, with the exception of Vantaa's `walktime`, where the group *Private or reserved* received a mean duration of 2.2 minutes (1.0 min).

The one-way ANOVA test for the explanatory variable `parkspot` and response variables `parktime` and `walktime` showed strong statistical significance for differences between parking spot types and study area municipalities. However, while the three largest study area municipalities had this state (Helsinki, Espoo, and Vantaa), Kauniainen received non-significant results from the ANOVA test for both `parktime` and `walktime`. In the cases of all study area municipalities, a better significance for differences between `parkspot` groups could be attained by excluding the group *Other*, if only slightly. When testing with a more limited set of *parkspot* groups, such as only testing differences of *Parking lot* and *Parking garage*, all statistical significance would be lost with the exception of Espoo, where statistical significance for the differences would position at $F = 5.266$, $p = 0.022$ ('*'). All municipalities except Kauniainen would also receive substantial statistical significance when testing for differences between the group *On the side of street* and *Private or reserved* ($F = 28.410$ in Espoo, $F = 126.548$ in Helsinki, and $F = 24.910$ in Vantaa, and all municipalities shared $p \leq 0.001$, '***').

Table 23. Parking times and walking times descriptive statistics with explanatory variable `parkspot`. The unit of median, mean, and standard deviation is minutes. The F value and p value presented are calculated in One-way Analysis of Variance test (ANOVA). P value significance codes: '***' $p \leq 0.001$, '**' $p \leq 0.01$, '*' $p \leq 0.05$, '.' $p \leq 0.1$, 'ns' $p \leq 1$.

			parktime					walktime				
		n	Median	Mean	Std.dev	Std.err	F value, p value	Median	Mean	Std.dev	Std.err	F value, p value
Espoo	On the side of street	150	3	4.15	3.91	0.32		3	3.97	3.01	0.25	
	Parking lot	363	2	2.91	3.66	0.19		2	3.33	3.28	0.17	
	Parking garage	171	3	3.64	2.90	0.22		3	3.95	2.53	0.19	
	Private or reserved	49	1	1.12	1.24	0.18		1	1.88	1.82	0.26	
	Other	13	2	4.08	7.89	2.19		2	4.23	5.66	1.57	
	Total	746	2	3.23	3.63	0.13	8.323, < 0.001 (***)	2	3.52	3.09	0.11	5.750, < 0.001 (***)
Helsinki	On the side of street	2241	5	6.35	6.08	0.13		5	5.12	4.06	0.09	
	Parking lot	817	2	3.91	4.78	0.17		3	4.35	4.34	0.15	
	Parking garage	522	3	4.01	3.85	0.17		5	5.01	3.94	0.17	
	Private or reserved	178	1	1.19	2.12	0.16		1	1.98	2.39	0.18	
	Other	19	2	3.00	3.51	0.81		1	2.95	3.41	0.78	
	Total	3777	4	5.24	5.60	0.09	68.395, < 0.001 (***)	4	4.78	4.10	0.07	29.022, < 0.001 (***)
Kauniainen	On the side of street	3	1	2.33	2.31	1.33		1	2.33	2.31	1.33	
	Parking lot	17	2	2.35	1.54	0.37		2	2.41	1.12	0.27	
	Parking garage	—	—	—	—	—		—	—	—	—	
	Private or reserved	2	0.5	0.50	0.71	0.50		1	1.00	0.00	0.00	
	Other	1	1	1.00	—	—		1	1.00	—	—	
	Total	23	2	2.13	1.60	0.33	0.976, 0.425 (*ns*)	2	2.22	1.28	0.27	1.055, 0.391 (*ns*)
Vantaa	On the side of street	108	4	5.81	6.09	0.59		4.5	5.15	4.98	0.48	
	Parking lot	341	2	3.51	4.25	0.23		2	3.62	3.76	0.20	
	Parking garage	127	3	4.06	4.33	0.38		4	4.81	4.32	0.38	
	Private or reserved	55	1	1.49	2.76	0.37		1	2.18	2.58	0.35	
	Other	6	1	2.50	3.83	1.57		1	2.17	3.87	1.58	
	Total	637	2	3.82	4.65	0.18	9.437, < 0.001 (***)	3	3.98	4.11	0.16	7.354, < 0.001 (***)
All	**Total**	5183	3	4.76	5.29	0.07	111.008, < 0.001 (***)	3	4.49	3.99	0.06	51.508, < 0.001 (***)

A view to the thesis survey data variables `parktime` and `walktime` through explanatory variable `likert` point out that area familiarity does not translate into efficient searching for parking or short walks from one's car to the final destination of one's journey (table 24). In the survey data, respondents reported finding parking places as fast or faster if they didn't know the area of parking at all (*Extremely familiar* versus *Not at all familiar*, only excepting Kauniainen). However, in the case of *Not at all familiar* the conclusion may be noise due to small group sizes across all study area municipalities. These mean ranges were 4.1–4.8 min (2.5–3.0 min median), 2.1–3.5 min (2.0–1.0 min), 2.67–2.66 min (2.5–1.0 min), and 3.0–1.8 min (3.0–1.0 min) for Helsinki, Vantaa, Espoo, and Kauniainen, respectively. It is noteworthy that there are major disparities in the mean and median of `parktime` in some of the `likert` values, such as Vantaa's *Extremely familiar* group, where mean is 3.5 minutes and median 1.0 minutes.

Response variable `walktime` behaved similarly to `parktime` when viewed with explanatory variable `likert`. Values *Extremely familiar* and *Not at all familiar* tended to be lowest, with the total sequence of mean or median creating graphs approximately shaped like bells.

The statistical significance of differences between groups for the explanatory variable `likert` were varying. Helsinki and Espoo received a p value under 0.01 from the one-way ANOVA test, while this identical test for Vantaa and Kauniainen ended in a non-significant conclusion. Conducting ANOVA test for a contained set of `likert` groups did not markedly change the statistical significance result of the differences between groups inside municipalities. In most combinations, removing *Not at all familiar* would improve the p value result but not as much as to change the significance code. Conversely, in most `parktime` and `walktime` combinations, the absence of *Extremely familiar* would worsen the p value. For example, Helsinki's strong `walktime` results can be undone by stripping the group *Extremely familiar* from the ANOVA test, providing a statistically non-significant output. From Vantaa's mostly non-significant ANOVA results, a low statistical significance for `parktime` could be gained from the differences of groups *Moderately familiar* and *Not at all familiar* ($F = 2.936$, $p = 0.088$, '.'). Using the same groups, an equivalent result was found with `walktime` ($F = 3.459$, $p = 0.064$, '.').

Table 24. Parking times and walking times descriptive statistics with explanatory variable `likert`. The unit of median, mean, and standard deviation is minutes. The F value and p value presented are calculated in One-way Analysis of Variance test (ANOVA). P value significance codes: '***' $p \leq 0.001$, '**' $p \leq 0.01$, '*' $p \leq 0.05$, '.' $p \leq 0.1$, 'ns' $p \leq 1$.

			parktime					walktime				
		n	Median	Mean	Std.dev	Std.err	F value, p value	Median	Mean	Std.dev	Std.err	F value, p value
Espoo	Extremely familiar	306	1	2.66	3.30	0.19		2	3.12	3.07	0.18	
	Moderately familiar	224	3	3.68	3.51	0.23		3	3.75	2.87	0.19	
	Somewhat familiar	130	2	3.35	3.52	0.31		3	3.64	2.70	0.24	
	Slightly familiar	74	2	4.08	5.08	0.59		3	4.39	4.20	0.49	
	Not at all familiar	12	2.5	2.67	1.61	0.47		2	2.67	1.97	0.57	
	Total	746	2	3.23	3.63	0.13	3.936, 0.004 (**)	2	3.52	3.09	0.11	3.375, 0.009 (**)
Helsinki	Extremely familiar	1695	3	4.84	5.63	0.14		3	4.17	3.85	0.09	
	Moderately familiar	1172	5	5.94	6.09	0.18		5	5.35	4.26	0.12	
	Somewhat familiar	572	4	5.07	4.58	0.19		5	5.06	3.77	0.16	
	Slightly familiar	282	4	5.24	4.98	0.30		5	5.59	4.99	0.30	
	Not at all familiar	56	2.5	4.12	4.96	0.66		3.5	4.59	3.62	0.48	
	Total	3777	4	5.24	5.60	0.09	7.508, < 0.001 (***)	4	4.78	4.10	0.07	18.793, < 0.001 (***)
Kauniainen	Extremely familiar	14	1	1.79	1.58	0.42		2	2.21	1.37	0.37	
	Moderately familiar	2	3.5	3.50	3.54	2.50		3	3.00	2.83	2.00	
	Somewhat familiar	4	2	1.75	0.50	0.25		2	1.75	0.50	0.25	
	Slightly familiar	2	3.5	3.50	0.71	0.50		2.5	2.50	0.71	0.50	
	Not at all familiar	1	3	3.00	—	—		2	2.00	—	—	
	Total	23	2	2.13	1.60	0.33	1.025, 0.421 (*ns*)	2	2.22	1.28	0.27	0.309, 0.868 (*ns*)
Vantaa	Extremely familiar	267	1	3.51	4.93	0.30		2	3.68	4.05	0.25	
	Moderately familiar	198	3	4.19	4.28	0.30		3	4.34	4.12	0.29	
	Somewhat familiar	99	2	4.10	4.79	0.48		3	4.48	4.73	0.48	
	Slightly familiar	59	2	3.92	4.74	0.62		2	3.64	3.47	0.45	
	Not at all familiar	14	2	2.21	1.42	0.38		2	2.29	1.38	0.37	
	Total	637	2	3.82	4.65	0.18	1.114, 0.349 (*ns*)	3	3.98	4.11	0.16	1.817, 0.124 (*ns*)
All	**Total**	5183	3	4.76	5.29	0.07	10.132, < 0.001 (***)	3	4.49	3.99	0.06	20.354, < 0.001 (***)

Viewing response variables `parktime` and `walktime` through the explanatory variable `artificial` shows that parking times and walking times are generally longer the more built the urban environment is (table 25). This variable was calculated using spatial data in the data processing phase of this thesis. The subsection 3.6, Processing survey data explains in detail the development procedure of `artificial`. Because each postal code area is assigned a singular `artificial` value, Kauniainen does not yield meaningful additional information in this context.

The explanatory variable `parktime` values follow a descending trend from the most intensively built group *Fully built* to the group representing areas of most scattered urban features, *Scarcely built*. In Helsinki, parking one's car took longest in the areas designated *Predominantly built* (mean 5.4 minutes, median 5.0 minutes), with *Fully built* following as the second longest (5.3, 4.0 min). In Espoo and Vantaa, the longest parking times could be found in fully built areas (Espoo's mean 3.6 minutes, median 2.0 minutes, while in Vantaa corresponding values were 5.1 minutes and 4.0 minutes).

The variable `walktime` does not offer such a clear downward trend as `parktime` does. In Helsinki, the longest walks from one's car to the final destination of one's journey was in the areas marked *Fully built*, with a mean duration of 4.8 minutes (4.0 minutes median). However, the groups `Predominantly built`, `Moderately built`, and `Some built` were close runners-up. In Vantaa, longest walking times were recorded in the group *Fully built* with 5.7 minutes mean and 5.0 minutes median, and in Espoo, the highest value recorded in *Scarcely built*, with 4.3 minutes mean and 3.0 minutes median, is a detail worthy of attention.

As for the ANOVA test, `artificial` produces strong statistical significances for differences between groups in applicable municipalities, but not for all municipalities. For example, the p value for Helsinki's `walktime` received $F = 2.009$ and $p \leq 0.090$ (.), a weak result compared to other variables and municipalities. Comparing specific groups instead of all of them, statistically significant sections could be identified most frequently in Vantaa. For example, there is a $p \leq 0.001$ ('***') statistical significance between the differences of the groups *Fully built* and *Some built*. This was true for both `parktime` ($F = 19.293$) and `walktime` ($F = 24.186$). In contrast, testing *Fully built–Scarcely built* gives non-significant results for both `parktime` ($F = 0.015$, $p = 0.902$) and `walktime` ($F = 0.035$, $p = 0.851$) in Vantaa.

Table 25. Parking times and walking times descriptive statistics with explanatory variable `artificial`. The unit of median, mean, and standard deviation is minutes. The F value and p value presented are calculated in One-way Analysis of Variance test (ANOVA). P value significance codes: '***' $p \leq 0.001$, '**' $p \leq 0.01$, '*' $p \leq 0.05$, '.' $p \leq 0.1$, 'ns' $p \leq 1$.

			parktime					walktime				
		n	Median	Mean	Std.dev	Std.err	F value, p value	Median	Mean	Std.dev	Std.err	F value, p value
Espoo	Fully built	405	2	3.64	3.94	0.20		3	3.81	3.16	0.16	
	Predominantly built	177	2	2.93	2.97	0.22		2	3.11	2.63	0.20	
	Moderately built	55	1	2.27	2.64	0.36		2	2.42	1.91	0.26	
	Some built	61	1	2.59	2.91	0.37		2	3.20	3.00	0.38	
	Scarcely built	48	2	2.77	4.44	0.64		3	4.29	4.50	0.65	
	Total	746	2	3.23	3.63	0.13	3.237, 0.012 (*)	2	3.52	3.09	0.11	4.431, 0.001 (**)
Helsinki	Fully built	2519	4	5.31	5.77	0.11		4	4.85	4.10	0.08	
	Predominantly built	1007	5	5.44	5.36	0.17		4	4.67	3.93	0.12	
	Moderately built	190	2	3.89	4.63	0.34		3	4.75	4.92	0.36	
	Some built	55	2	3.16	3.95	0.53		3	4.24	4.30	0.58	
	Scarcely built	6	0	0.67	0.82	0.33		1	0.83	0.75	0.31	
	Total	3777	4	5.24	5.60	0.09	6.097, < 0.001 (***)	4	4.78	4.10	0.07	2.009, 0.090 (.)
Kauniainen	Fully built	23	2	2.13	1.60	0.33		2	2.22	1.28	0.27	
	Predominantly built	—	—	—	—	—		—	—	—	—	
	Moderately built	—	—	—	—	—		—	—	—	—	
	Some built	—	—	—	—	—		—	—	—	—	
	Scarcely built	—	—	—	—	—		—	—	—	—	
	Total	23	2	2.13	1.60	0.33	—	2	2.22	1.28	0.27	—
Vantaa	Fully built	204	4	5.11	5.23	0.37		5	5.67	5.16	0.36	
	Predominantly built	180	2	3.28	3.57	0.27		2	3.17	2.61	0.19	
	Moderately built	184	2	3.44	4.89	0.36		2	3.37	3.78	0.28	
	Some built	60	1	2.03	2.59	0.33		2	2.32	2.00	0.26	
	Scarcely built	9	2	5.33	8.03	2.68		3	5.33	6.16	2.05	
	Total	637	2	3.82	4.65	0.18	7.587, < 0.001 (***)	3	3.98	4.11	0.16	15.331, < 0.001 (***)
All	**Total**	5183	3	4.76	5.29	0.07	18.333, < 0.001 (***)	3	4.49	3.99	0.06	11.757, < 0.001 (***)

A persisting descending trend is observed in the values of `parktime` and `walktime` when the data is viewed with the explanatory variable of `ykr_zone` (table 26). This variable was calculated using spatial data in the data processing phase of this thesis. The subsection 3.6, Processing survey data explains in detail this development process. As in the case of the variable `artificial`, `ykr_zone` is a singular value assigned each postal code area in the reseach area, resulting in meager additional information gain from the municipality of Kauniainen. Additionally, due to their urban structure and the method of the original spatial data, not all `ykr_zone` groups are present in Espoo and Vantaa.

Longest `parktime` values were recorded in the groups *Keskustan jalankulkuvyöhyke* and *Keskustan reunavyöhyke*, these groups can only be assigned to areas that are in the immediate vicinity of a regional center, Helsinki in this case. In the center of Helsinki, parking received a mean duration of 7.6 minutes (5.0 minutes median). In Espoo and Vantaa, the group with longest parking times was *Alakeskuksen jalankulkuvyöhyke*, with 3.8 minutes mean (3.0 min) for Espoo and 4.5 minutes mean (3.0 min) for Vantaa. In all study area municipalities, parking times steadily shortened with each consecutive group, excluding the group *novalue*.

Longest walking times from one's parked car to the journey's end is observed in Helsinki's *Keskustan* *jalankulkuvyöhyke* with a mean duration of 6.4 minutes (5.0 min median). Espoo's longest `walktime` value was in *Alakeskuksen jalankulkuvyöhyke* with a 4.1 minutes mean duration (3.0 min). In Vantaa, some northern postal code areas received `walktime` values that can be considered aberrations, causing the longest walking times appear in the group *novalue* with a mean duration of 4.9 minutes and 3.0 minutes median.

Strong statistical significances were found for the explanatory variable `ykr_zone` in the ANOVA test. All test combinations with `ykr_zone` produced $p \leq 0.001$, with the exception of Vantaa's `parktime` ($F = 4.001$, $p = 0.003$, '**'). This result could be slightly improved by excluding the group *novalue* from the ANOVA test. In other combinations, the statistical significance was sufficiently strong so that this same removal had a negligible effect in test results. Carrying out the ANOVA test with a narrower set of groups produced, too, statistically strong results. Some exceptions, however, could be found. In Espoo, where an ANOVA test with the groups *Alakeskuksen jalankulkuvyöhyke*, *Intensiivinen joukkoliikennevyöhyke*, and *novalue* resulted in a non-significant result ($F = 1.806$, $p = 0.165$). The same non-significant results were achieved with the same groups in Vantaa, using `parktime` or `walktime` ($F = 1.212$, $p = 0.298$, and $F = 0.814$, $p = 0.444$, respectively).

Table 26. Parking times and walking times descriptive statistics with explanatory variable `ykr_zone`. The unit of median, mean, and standard deviation is minutes. The F value and p value presented are calculated in One-way Analysis of Variance test (ANOVA). P value significance codes: '***' $p \leq 0.001$, '**' $p \leq 0.01$, '*' $p \leq 0.05$, '.' $p \leq 0.1$, 'ns' $p \leq 1$.

			parktime					walktime				
		n	Median	Mean	Std.dev	Std.err	F value, p value	Median	Mean	Std.dev	Std.err	F value, p value
Espoo	Keskustan jalankulkuvyöhyke	—	—	—	—	—		—	—	—	—	
	Keskustan reunavyöhyke	—	—	—	—	—		—	—	—	—	
	Alakeskuksen jalankulkuvyöhyke	211	3	3.78	3.62	0.25		3	4.12	2.98	0.20	
	Intensiivinen joukkoliikennevyöhyke	278	2	3.72	4.05	0.24		3	3.58	3.02	0.18	
	Joukkoliikennevyöhyke	57	1	2.07	2.01	0.27		2	2.07	1.57	0.21	
	Autovyöhyke	99	1	1.93	2.23	0.22		2	2.59	2.86	0.29	
	novalue	101	2	2.65	3.71	0.37		3	3.85	3.85	0.38	
	Total	746	2	3.23	3.63	0.13	8.040, < 0.001 (***)	2	3.52	3.09	0.11	8.026, < 0.001 (***)
Helsinki	Keskustan jalankulkuvyöhyke	1157	5	7.60	6.42	0.19		5	6.36	4.42	0.13	
	Keskustan reunavyöhyke	1240	4	5.39	5.69	0.16		4	4.88	4.14	0.12	
	Alakeskuksen jalankulkuvyöhyke	286	3	3.92	3.36	0.20		3	4.10	3.25	0.19	
	Intensiivinen joukkoliikennevyöhyke	761	2	3.07	3.68	0.13		2	3.22	3.19	0.12	
	Joukkoliikennevyöhyke	167	1	2.23	3.53	0.27		2	2.72	2.84	0.22	
	Autovyöhyke	18	1	1.56	1.54	0.36		1	2.28	2.30	0.54	
	novalue	148	2	3.01	3.57	0.29		3	3.61	3.31	0.27	
	Total	3777	4	5.24	5.60	0.09	77.835, < 0.001 (***)	4	4.78	4.10	0.07	64.204, < 0.001 (***)
Kauniainen	Keskustan jalankulkuvyöhyke	—	—	—	—	—		—	—	—	—	
	Keskustan reunavyöhyke	—	—	—	—	—		—	—	—	—	
	Alakeskuksen jalankulkuvyöhyke	—	—	—	—	—		—	—	—	—	
	Intensiivinen joukkoliikennevyöhyke	—	—	—	—	—		—	—	—	—	
	Joukkoliikennevyöhyke	23	2	2.13	1.60	0.33		2	2.22	1.28	0.27	
	Autovyöhyke	—	—	—	—	—		—	—	—	—	
	novalue	—	—	—	—	—		—	—	—	—	
	Total	23	2	2.13	1.60	0.33	—	2	2.22	1.28	0.27	—
Vantaa	Keskustan jalankulkuvyöhyke	—	—	—	—	—		—	—	—	—	
	Keskustan reunavyöhyke	—	—	—	—	—		—	—	—	—	
	Alakeskuksen jalankulkuvyöhyke	260	3	4.46	4.72	0.29		3	4.34	3.91	0.24	
	Intensiivinen joukkoliikennevyöhyke	88	2	4.23	5.38	0.57		2	4.26	5.00	0.53	
	Joukkoliikennevyöhyke	68	2	3.21	4.58	0.55		2	2.78	2.70	0.33	
	Autovyöhyke	98	1	2.43	3.62	0.37		2	2.42	2.43	0.25	
	novalue	123	2	3.64	4.49	0.40		3	4.91	4.99	0.45	
	Total	637	2	3.82	4.65	0.18	4.001, 0.003 (**)	3	3.98	4.11	0.16	7.475, < 0.001 (***)
All	**Total**	5183	3	4.76	5.29	0.07	112.502, < 0.001 (***)	3	4.49	3.99	0.06	88.815, < 0.001 (***)

4.3 Travel time comparison application findings

Utilising the travel time comparison application, we can find results pertaining to the third research question of this thesis: *What is the significance of the parking process to the overall travel time?* In the application, the data of interest is denoted as `pct`. This is a percentual depiction of how much the parking process covers of an entire travel chain from an origin postal code area to a destination postal code area (figure 25). We will approach these results by selecting examples – specific origin postal code areas – using the explanatory variable `ykr_zone` groups to examine urban areas different from each other (figure 19). One postal code area was selected from each `ykr_zone` group by finding the group mean population in the entire study area and the postal code area closest to that value (table 27, figure 33). In this subsection, the thesis data `pct` is of interest. The calculation method for `ykr_zone` is explained in table 19.

Table 27. Zones of urban structure and postal code area example selections. Population data is from PAAVO postal code areas dataset (Statistics Finland 2019).

Zone of urban structure (YKR zone)	YKR zone population mean	Selected postal code area	Postal code area population
Center walking zone	9556.80	00150 Eira - Hernesaari	9496
Center periphery zone	6835.83	00520 Itä-Pasila	7306
Subcenter walking zone	10335.75	02650 Pohjois-Leppävaara	10595
Intensive transit zone	8157.93	00640 Oulunkylä-Patola	8171
Transit zone	5506.68	00430 Maununneva	5454
Automobile zone	5309.24	02920 Niipperi	5347
novalue	4760.67	01690 Ylästö	4787

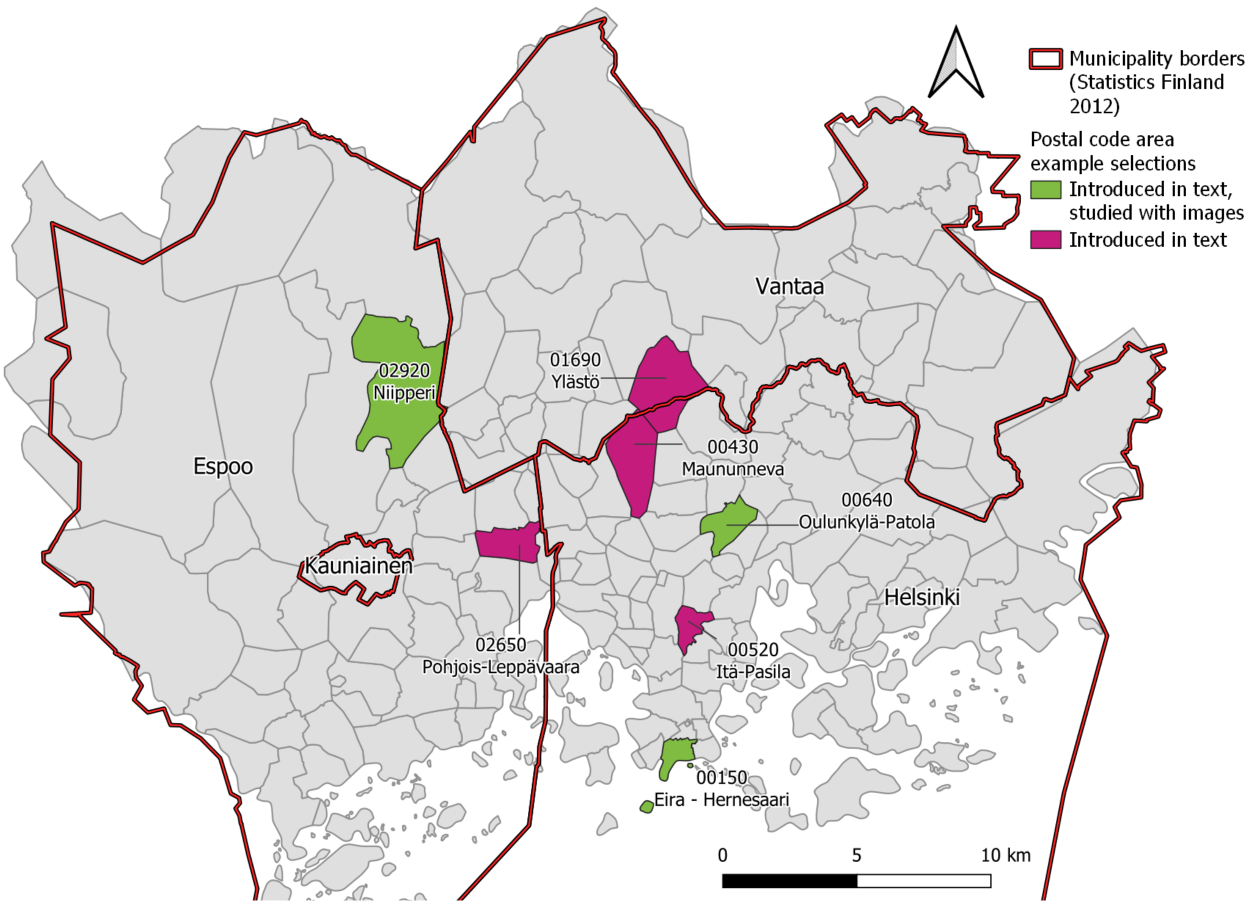


Figure 33. These postal code represent each zone of urban structure and as such they have been selected for a closer look in this chapter.

The selected postal code areas represent functionally different parts of the study area. 00150 Eira-Hernesaari (Center walking zone) is located at the southern tip of the peninsula of Helsinki where all possible travel options for private car are time intensive. 00520 Itä-Pasila (Center periphery zone) is in the immediate vicinity of the center of Helsinki, is densely built, and is equipped with better travel options for the private car than Eira-Hernesaari. 02650 Pohjois-Leppävaara (Subcenter walking zone) represents an important subcenter in the study area with large amounts of office space, a major shopping mall, and a large population. It is a major residential area in Espoo, and it has a good access to major roads. 00640 Oulunkylä-Patola (Intensive transit zone) is also mostly a residential area with extensive public transport connections as well as access to major road infrastructure of the Helsinki Capital Region, namely the Ring I beltway and the Finnish national road 3 to Tampere. 00430 Maununneva (Transit zone) is a residential area situated just next to the Finnish national highway 3, but with limited motorway interchanges. Its eastern side hugs the Central Park of Helsinki and is littered with small neighborhood roads. 02920 Niipperi (Automobile zone) is characterised as an area of detached housing where public transport coverage is scarce. 01690 Ylästö (novalue) was selected to represent postal code areas which were outside of the YKR zones classification according to the thesis calculation method (see appendices I and II for locations of these areas). These areas can be centers of local activity, but lack a combination of population, commercial interaction and public transport connections to belong in any of the proper `ykr_zone` groups (Ristimäki et al. 2017). These areas are used as representatives of the whole study area, as the breadth of the data available in the travel time comparison application is much too plentiful to be presented in full in tables or individual images. The results will delve further into the proportion of the parking process in the cases of 00150 Eira-Hernesaari, 00640 Oulunkylä-Patola, and 02920 Niipperi. The results for the remaining four postal code areas may be viewed in appendices III–V, VI–VIII, IX–XI, and XII–XIV.

Table 28 presents the driving segments and parking process segments of several different example travel chains. In these examples, the parking process is a significant part of the travel chains. In most cases, the parking process share diminishes the longer the travel chain is in duration and kilometers, but driving to the center of Helsinki is an exception because of the long mean `parktime` and `walktime` values. When comparing the parking process length between the thesis survey and the durations used in the *Travel Time Matrix*, thesis parking process can be up to six times longer than that in the *Travel Time Matrix*.

Table 28. Proportion of the parking process in example travel chains utilising the thesis survey data. Mean parking process duration is static data and does not change for individual destination postal code areas.

		Mean driving time duration, *TTM* data (min)			Mean parking process duration, survey data (min)			Parking process share of the total travel chain (%)		
Origin	Destination	rush	mid	all	rush	mid	all	rush	mid	all
00150 Eira - Hernesaari (Center walking zone)	00150	5.12	4.68	4.48	11.25	17.40	14.16	220*	372*	316*
	00520	24.21	20.25	18.53	13.59	11.67	13.58	56	58	73
	02650	33.50	29.16	26.20	4.11	7.47	7.08	12	26	27
	00640	34.18	29.11	26.48	5.00	7.33	6.09	15	25	23
	00430	37.53	32.49	29.27	6.34	8.33	4.47	17	26	15
	02920	52.02	43.61	40.94	4.00	6.00	4.33	8	14	11
	01690	48.06	41.74	37.90	0.00	7.00	3.75	0	17	10
00520 Itä-Pasila (Center periphery zone)	00150	22.89	18.87	17.38	11.25	17.40	14.16	49	92	81
	00520	6.77	5.47	5.11	13.59	11.67	13.58	201*	213*	266*
	02650	25.85	21.90	19.76	4.11	7.47	7.08	16	34	36
	00640	16.00	13.06	12.20	5.00	7.33	6.09	31	56	50
	00430	23.73	19.76	18.25	6.34	8.33	4.47	27	42	24
	02920	41.87	34.71	32.36	4.00	6.00	4.33	10	17	13
	01690	31.06	26.57	24.61	0.00	7.00	3.75	0	26	15
02650 Pohjois-Leppävaara (Subcenter walking zone)	00150	34.28	29.42	26.46	11.25	17.40	14.16	33	59	54
	00520	26.62	22.10	20.23	13.59	11.67	13.58	51	53	67
	02650	5.53	4.92	4.53	4.11	7.47	7.08	74	152*	156*
	00640	20.82	18.52	16.70	5.00	7.33	6.09	24	40	36
	00430	19.06	17.30	15.52	6.34	8.33	4.47	33	48	29
	02920	27.51	23.78	22.19	4.00	6.00	4.33	15	25	20
	01690	29.80	26.52	24.15	0.00	7.00	3.75	0	26	16
00640 Oulunkylä-Patola (Intensive transit zone)	00150	35.33	29.62	27.06	11.25	17.40	14.16	32	59	52
	00520	17.20	14.24	13.11	13.59	11.67	13.58	79	82	104*
	02650	20.83	18.17	16.50	4.11	7.47	7.08	20	41	43
	00640	4.44	3.87	3.71	5.00	7.33	6.09	113*	189*	164*
	00430	17.04	14.54	13.59	6.34	8.33	4.47	37	57	33
	02920	35.87	30.31	28.39	4.00	6.00	4.33	11	20	15
	01690	23.76	20.42	19.24	0.00	7.00	3.75	0	34	19
00430 Maununneva (Transit zone)	00150	38.60	32.89	29.82	11.25	17.40	14.16	29	53	47
	00520	24.58	21.01	19.05	13.59	11.67	13.58	55	56	71
	02650	17.32	15.60	14.07	4.11	7.47	7.08	24	48	50
	00640	17.13	14.94	13.91	5.00	7.33	6.09	29	49	44
	00430	8.72	7.71	7.28	6.34	8.33	4.47	73	108*	61
	02920	29.62	25.98	23.87	4.00	6.00	4.33	14	23	18
	01690	17.51	15.74	14.77	0.00	7.00	3.75	0	44	25
02920 Niipperi (Automobile zone)	00150	54.19	44.85	41.98	11.25	17.40	14.16	21	39	34
	00520	42.85	35.41	33.00	13.59	11.67	13.58	32	33	41
	02650	26.80	23.17	21.61	4.11	7.47	7.08	15	32	33
	00640	36.58	30.88	28.90	5.00	7.33	6.09	14	24	21
	00430	29.15	25.82	23.73	6.34	8.33	4.47	22	32	19
	02920	9.75	8.97	8.49	4.00	6.00	4.33	41	67	51
	01690	29.31	25.95	24.08	0.00	7.00	3.75	0	27	16
01690 Ylästö (novalue)	00150	48.65	41.47	37.90	11.25	17.40	14.16	23	42	37
	00520	32.15	27.31	25.21	13.59	11.67	13.58	42	43	54
	02650	27.73	24.48	22.38	4.11	7.47	7.08	15	31	32
	00640	23.95	20.28	19.23	5.00	7.33	6.09	21	36	32
	00430	18.39	16.31	15.36	6.34	8.33	4.47	34	51	29
	02920	29.88	26.41	24.35	4.00	6.00	4.33	13	23	18
	01690	8.45	7.87	7.56	0.00	7.00	3.75	0	89	50

*Thesis research survey data parking process is longer than the entire driving time segment calculated from Helsinki Region Travel Time Matrix 2018.

The proportion of the parking process from the starting postal code area of 00150 Eira-Hernesaari appears relatively even when viewing the survey data with equal intervals. The southern part of the peninsula of Helsinki accumulates the largest parking process shares. In the `pct` data, additionally, it is quite commonplace to end up in a situation where the calculated parking process duration is longer than the calculated *Travel Time Matrix* mean driving time to a destination postal code area.

During rush hour traffic, the proportion of the parking process in travel chains starting from 00150 Eira-Hernesaari is the highest in the center of Helsinki (figure 34). Outside the center, 00670 Paloheinä, Helsinki (parking process 39 % of the total travel chain duration), 00870 Etelä-Laajasalo, Helsinki (43 %), and 01400 Rekola, Vantaa (66 %) stand out with lengthy parking processes compared to `drivetime`. In addition to the occasionally alarmingly long parking processes, some postal code areas report parking process proportions of zero %, according to the survey data. Some of these are, for example, 00830 Tammisalo in Helsinki, 02940 Lippajärvi-Järvenperä in Espoo, and 01690 Ylästö in Vantaa.

During midday traffic, the general outline of the parking process durations starting from 00150 Eira-Hernesaari stays similar compared to rush hour traffic (figure 35). Some particularly long parking processes may be found from 01750 Keimola, Vantaa (parking process 95 % of the total travel chain duration, an anomalous survey result), 00590 Kaitalahti, Helsinki (42 %), and 02100 Tapiola, Espoo (43 %). A midday parking process share of 0 % is only present in 02820 Nupuri-Nuuksio, Espoo.

Using all available survey data and the full *Travel Time Matrix* data, all postal code areas can be represented (figure 36). This data largely follows the trend of rush hour and midday data of the origin postal code area 00150 Eira-Hernesaari. Utilising this aggregated variable, long parking processes are found from 02100 Tapiola in Espoo (55 %), Kulosaari in Helsinki (58 %), and 00590 Kaitalahti in Helsinki (44 %). The parking process proportions of subcenters of the Helsinki Capital Region slightly stand out from the data, but this is an inconclusive observation as sparsely populated locations such as 01750 Keimola may also receive large parking process shares.

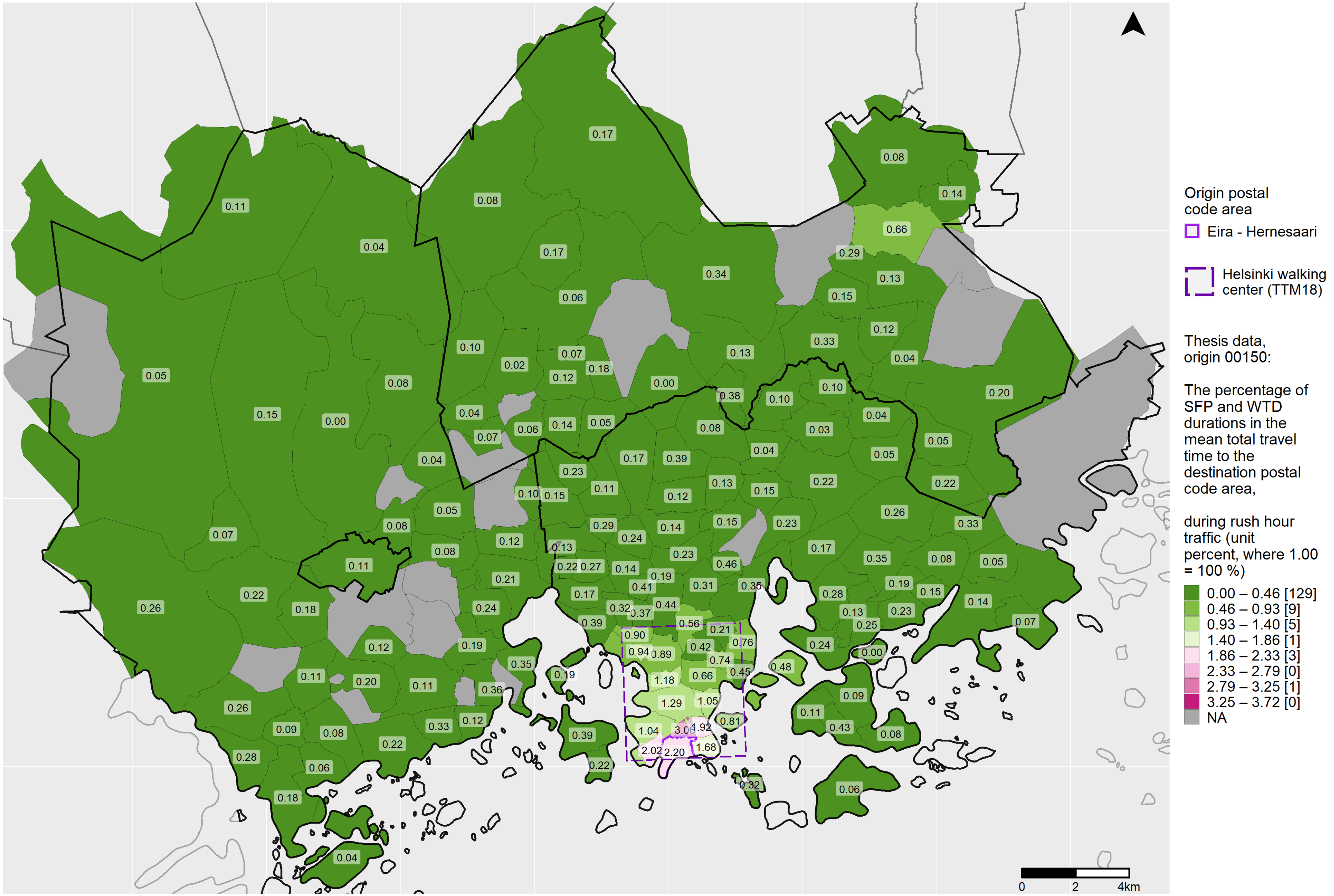


Figure 34. The parking process proportion in the total travel chain, in rush hour traffic, starting from 00150 Eira-Hernesaari. SFP stands for *searching for parking*, `parktime`, and WTD *walking to destination*, `walktime`. These are the components of the parking process in the *door-to-door approach.*

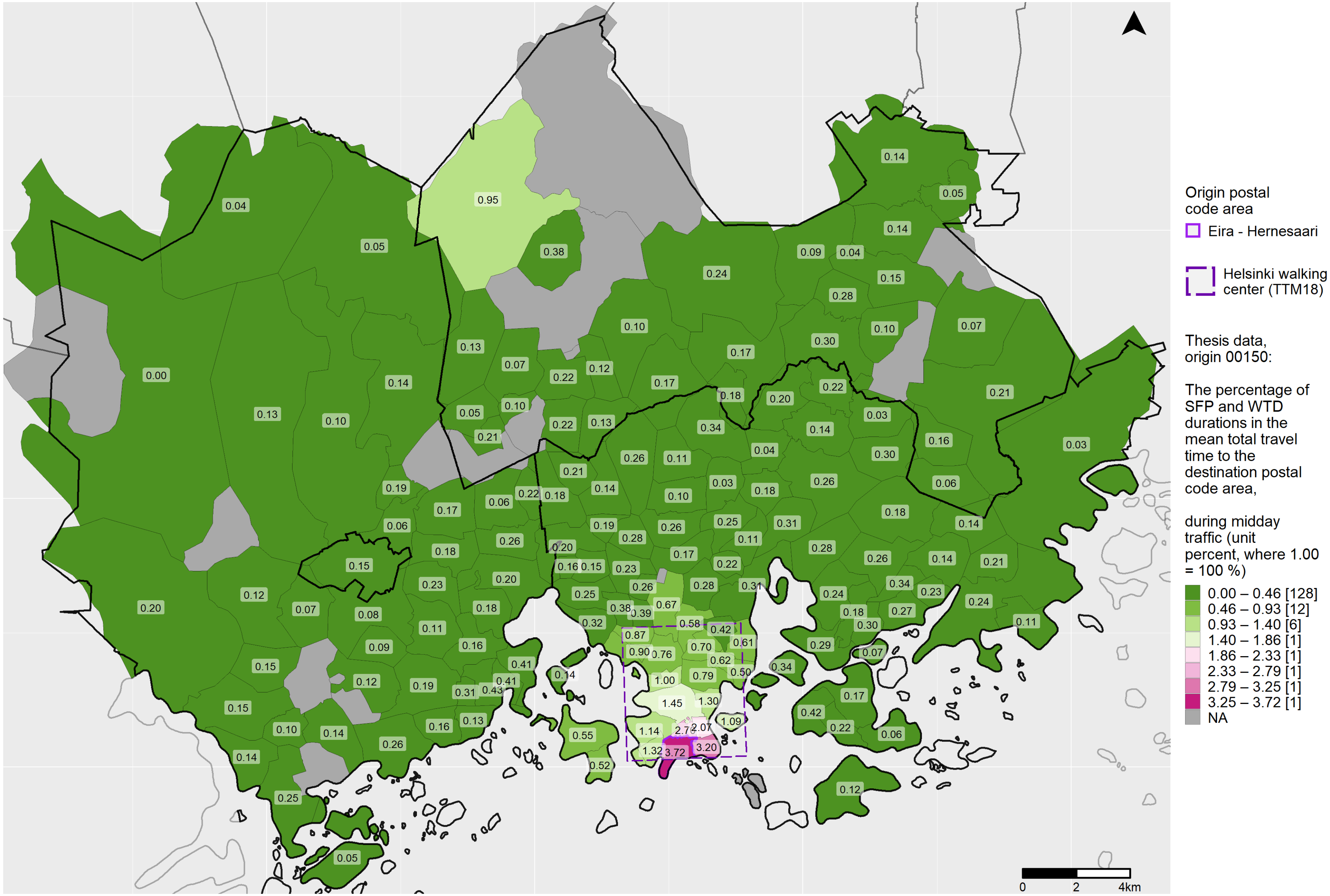


Figure 35. The parking process proportion in the total travel chain, in midday traffic, starting from 00150 Eira-Hernesaari.

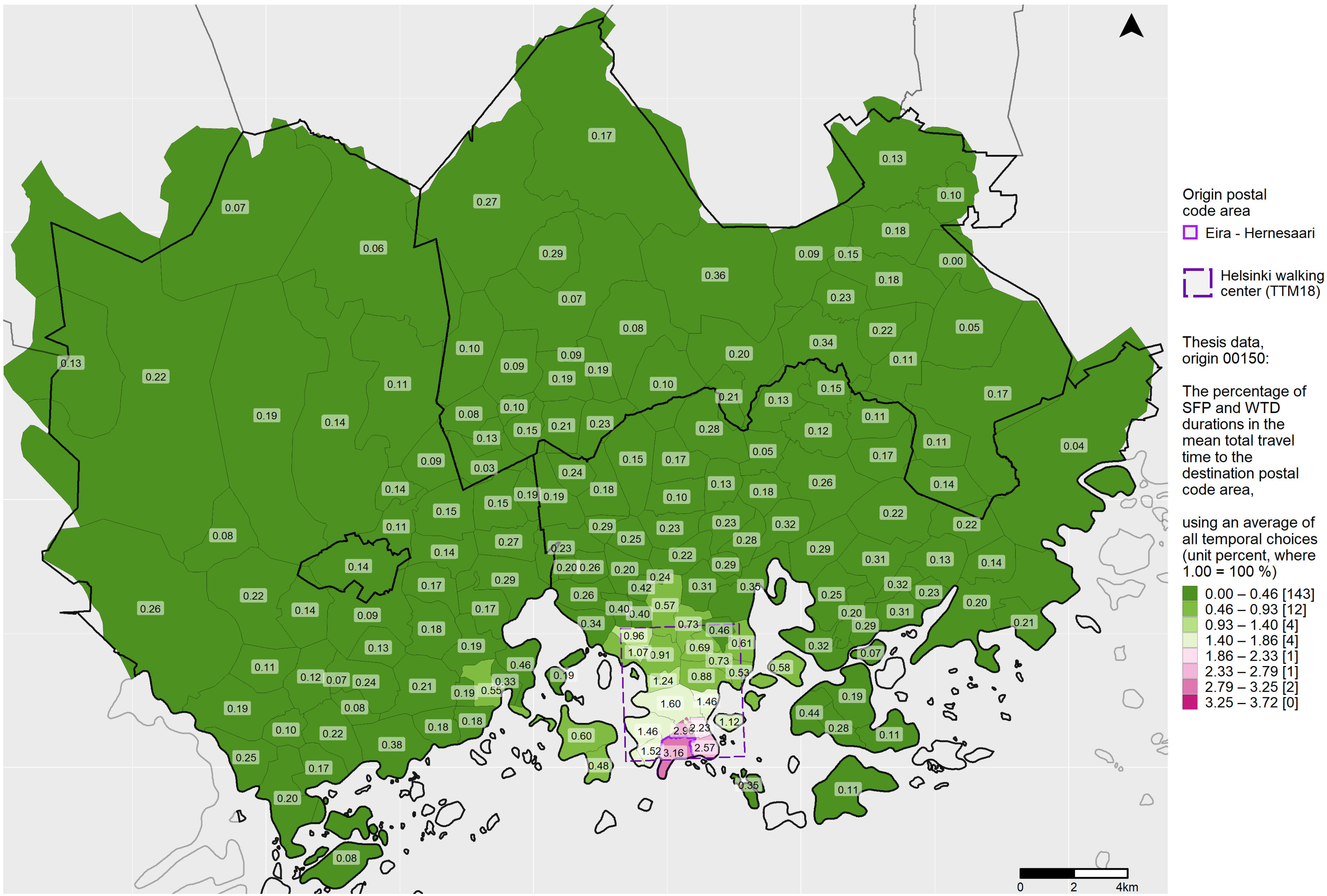


Figure 36. The parking process proportion in the total travel chain, using all available temporal values, starting from 00150 Eira-Hernesaari.

The proportion of the parking process fluctuates spatially when viewing the percentual data with 00640 Oulunkylä-Patola as the origin postal code area. For rush hour traffic, the largest shares of the total travel chains can be found in the general vicinity of the origin postal code area, with prongs extending to the center of Helsinki and to eastern Helsinki (figure 37). Excluding the destination postal code areas where the parking process is longer than the calculated `drivetime`, long parking process shares may be located at 00270 Pohjois-Meilahti in Helsinki (87 % of the total travel chain duration), 00920 Myllypuro in Helsinki (72 %), and 01530 Veromiehenkylä in Vantaa (68 %). It is notable that 00640 Oulunkylä-Patola has generally more valid percentual values (parking process share is less than the total driving segment of the travel chain) than 00150 Eira-Hernesaari as fewer postal code areas have their parking process durations exceed that of their `drivetime` values.

In midday traffic, the proportion of the parking process in travel chains from the origin 00640 Oulunkylä-Patola shows long parking process shares for the most parts of Helsinki and for a branch reaching northeast to Vantaa (figure 38). For midday traffic, long parking process shares are calculated for 01300 Tikkurila in Vantaa (68 %), and 00510 Etu-Vallila–Alppila in Helsinki (83 %). In most of Espoo, parking process shares are less than 30 %, with the largest found from 02650 Pohjois-Leppävaara in Espoo (41 %).

If all available temporal data is employed in thesis survey data and the *Travel Time Matrix*, extreme values recorded in `parktime` and `walktime` are honed away and a rough circular shape of long parking process shares may be observed around 00640 Oulunkylä-Patola (figure 39). Using this variable, the majority of the center of Helsinki receives parking process shares of more than 60 %. In general, most of the largest parking process shares are located inside the Ring I beltway with the exception of Vantaa's 01300 Tikkurila (76 %) and 01530 Veromiehenkylä (71 %).

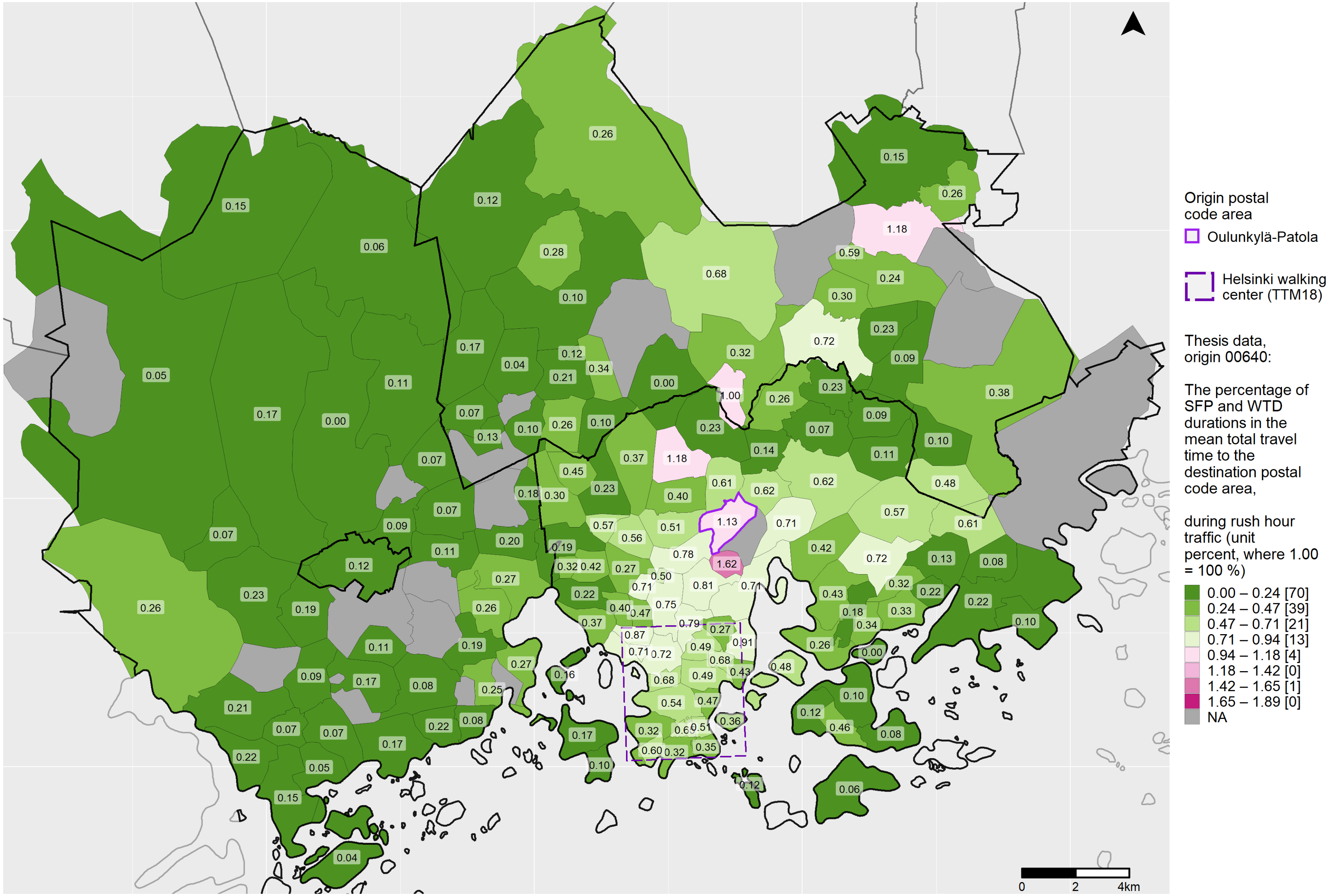


Figure 37. The parking process proportion in the total travel chain, in rush hour traffic, starting from 00640 Oulunkylä-Patola. SFP stands for *searching for parking*, `parktime`, and WTD *walking to destination*, `walktime`. These are the components of the parking process in the *door-to-door approach*.

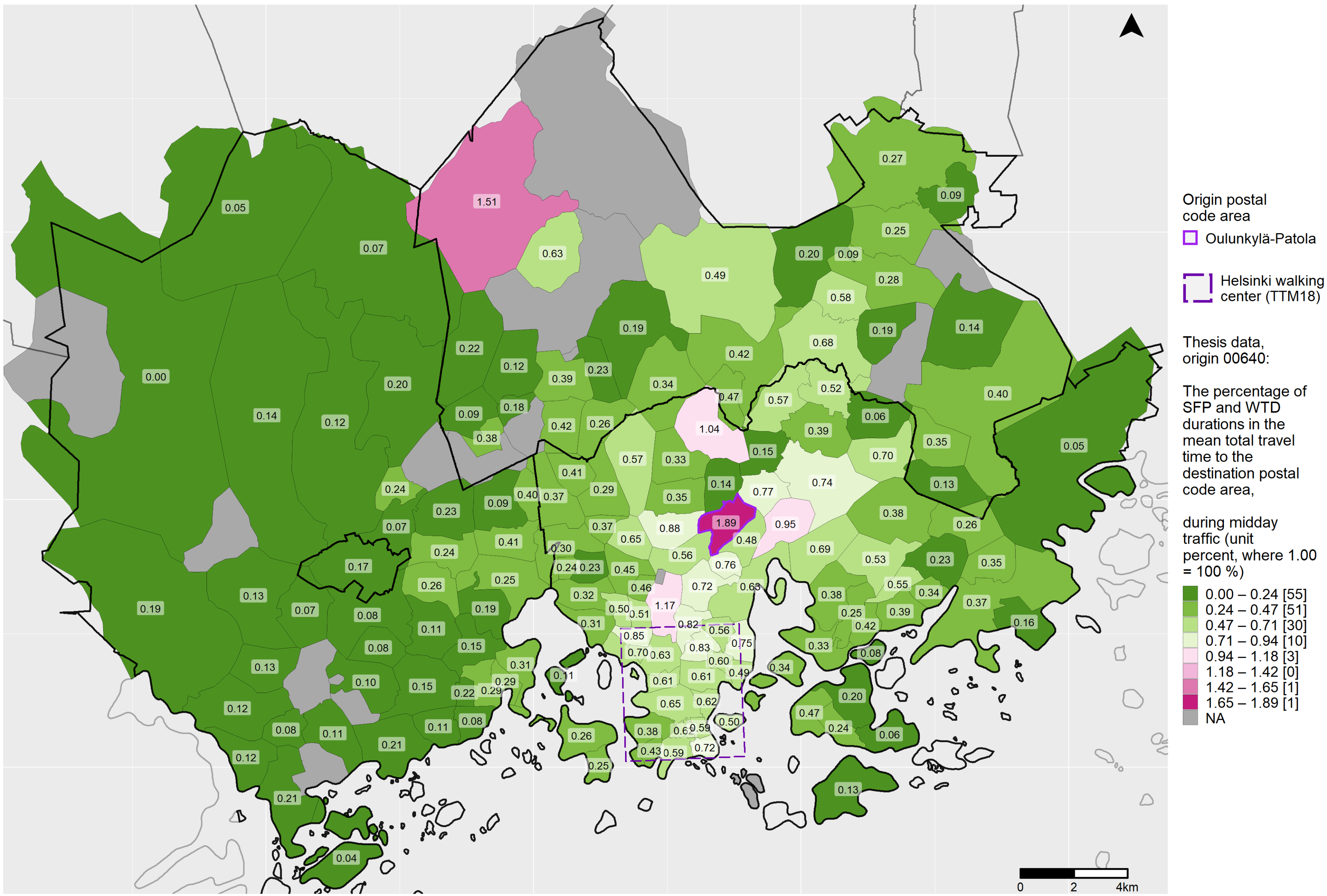


Figure 38. The parking process proportion in the total travel chain, in midday traffic, starting from 00640 Oulunkylä-Patola.

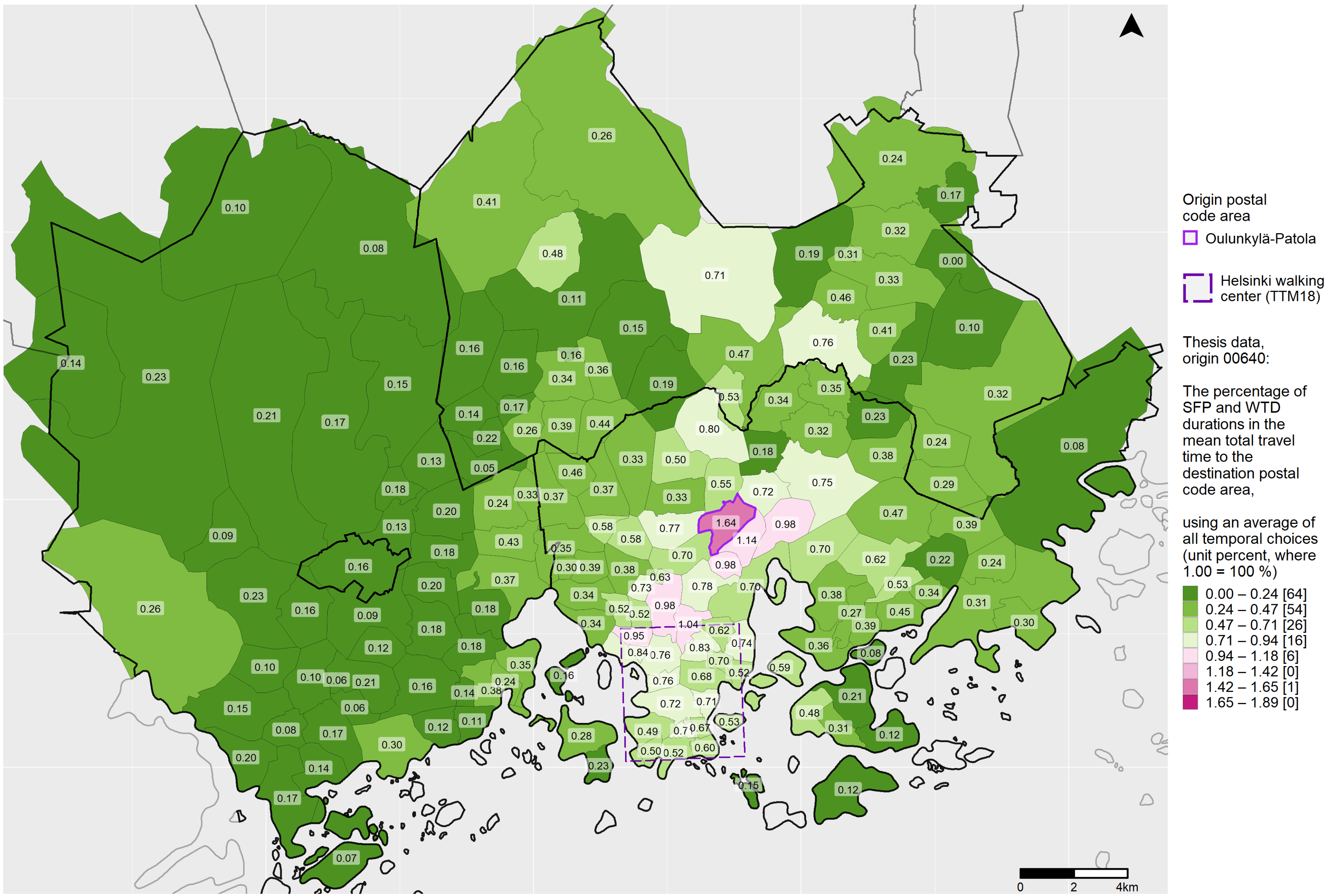


Figure 39. The parking process proportion in the total travel chain, using all temporal values, starting from 00640 Oulunkylä-Patola.

The proportion of the parking process in total travel chains starting from 02920 Niipperi, during rush hour traffic, is generally large in all parts of the Helsinki Capital Region (figure 40). In Espoo, long parking process shares are found from the beltway Ring III postal code areas such as 02780 Kauklahti (42 %), 02770 Espoon keskus (40 %), and 02740 Bemböle-Pakankylä (37 %). In Vantaa, the largest shares are found from 01400 Rekola (73 %), 01530 Veromiehenkylä (54 %), and 01520 Tammisto (49 %). Helsinki's largest parking process share is located in 00270 Pohjois-Meilahti (49 %) with all of the postal code areas of the center of Helsinki reaching lower shares. According to the survey and the *Travel Time Matrix* data, the parking process share in a rush hour traffic travel chain from Niipperi to 00160 Katajanokka is a proportionally low 19 %.

During midday traffic, the proportion of the parking process in travel chains starting from the origin postal code area of 02920 Niipperi shows relatively low values (figure 41). In fact, the largest parking process share in Espoo is found from the travel chain that starts and ends in Niipperi (67 %). All other values are equal to or below 40 %. In Helsinki, largest midday traffic parking process shares are found from 00270 Pohjois-Meilahti (47 %) and 00340 Länsi-Pasila (46 %) with the center of Helsinki again exhibiting lower parking process values across the board. In Vantaa, large parking process shares were located in 01700 Kivistö (70 %), 01710 Pähkinärinne (52 %), and 01680 Askisto (48 %).

When utilising all available data from the survey and the *Travel Time Matrix*, a comprehensive picture of the parking process proportion in travel chains from 02920 Niipperi can be gathered (figure 42). Many hotspots for large parking process shares may be studied in the different municipalities of Helsinki Capital Region, and no parking process duration is anomalously longer than the total driving segment in any particular travel chain. In Espoo, the largest parking process shares are located west from Niipperi, with 02940 Lippajärvi-Järvenperä (44 %) and 02740 Bemböle-Pakankylä (42 %) at the top. In Helsinki, northwestern part of the center of Helsinki stands out. The largest shares are located in 00270 Pohjois-Meilahti (52 %) and in 00290 Meilahden sairaala-alue (48 %). Vantaa's largest parking process shares were located in 01530 Veromiehenkylä (54 %) and 01700 Kivistö (52 %).

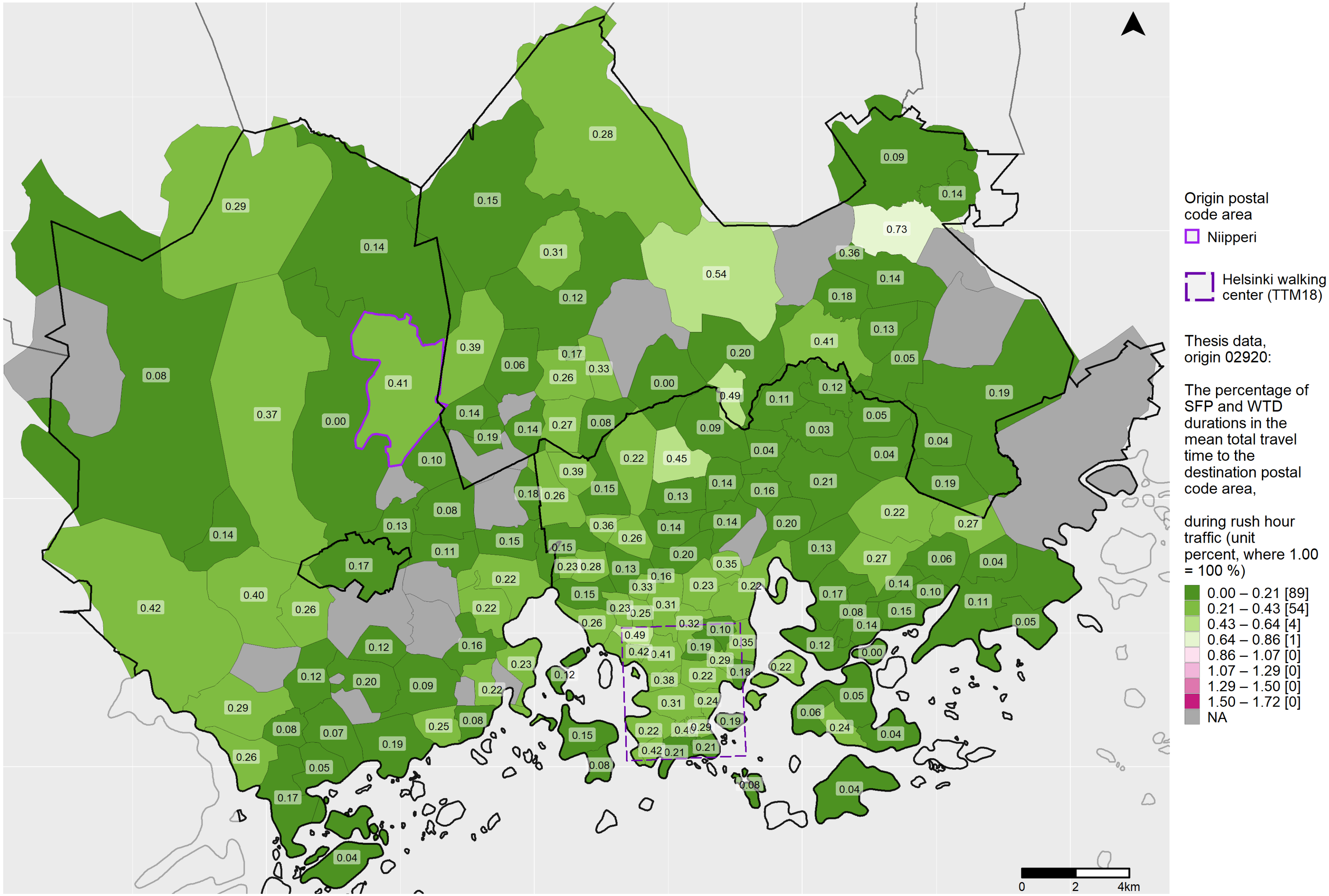


Figure 40. The parking process proportion in the total travel chain, in rush hour traffic, starting from 02920 Niipperi. SFP stands for *searching for parking*, `parktime`, and WTD *walking to destination*, `walktime`. These are the components of the parking process in the *door-to-door approach.*

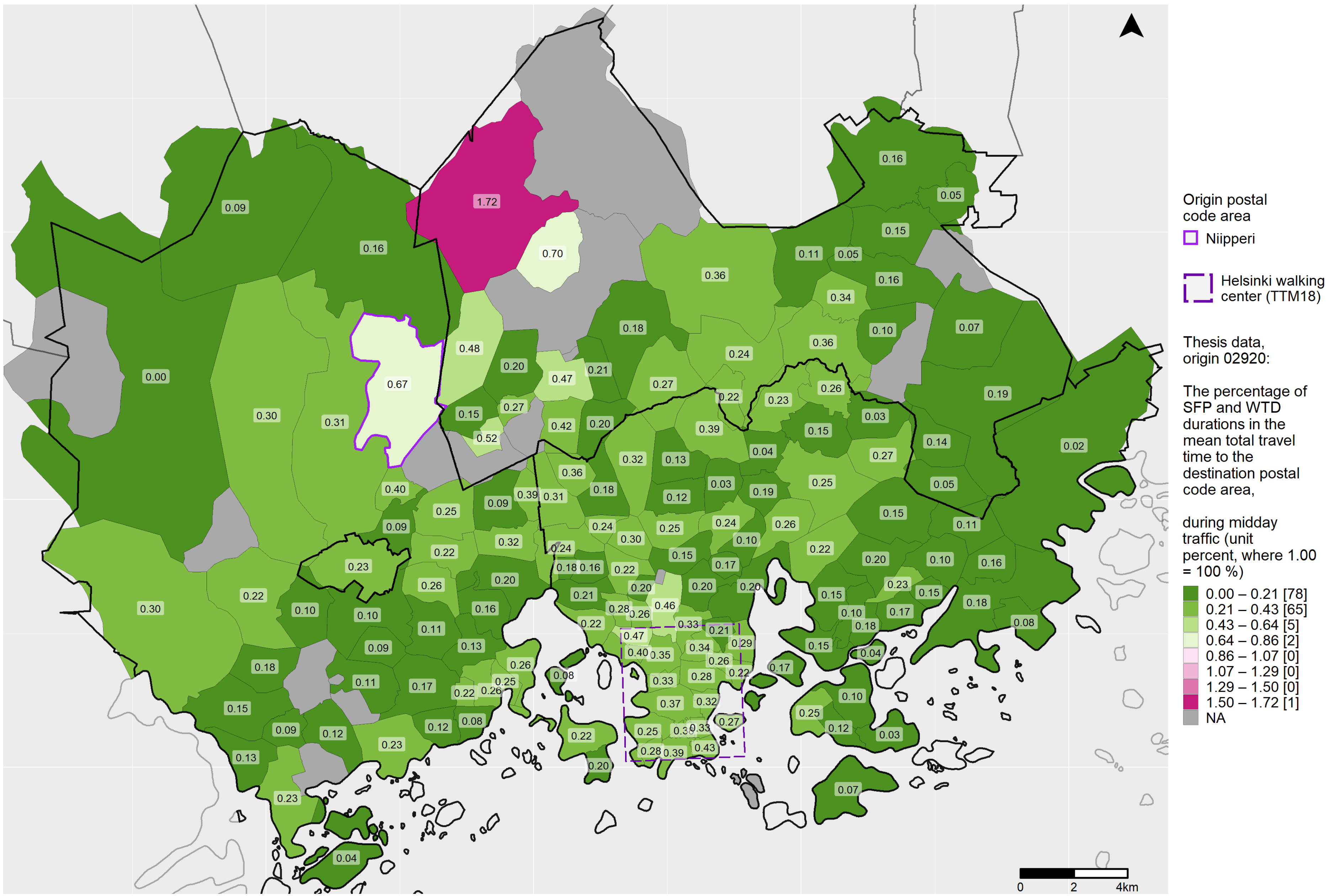


Figure 41. The parking process proportion in the total travel chain, in midday traffic, starting from 02920 Niipperi.

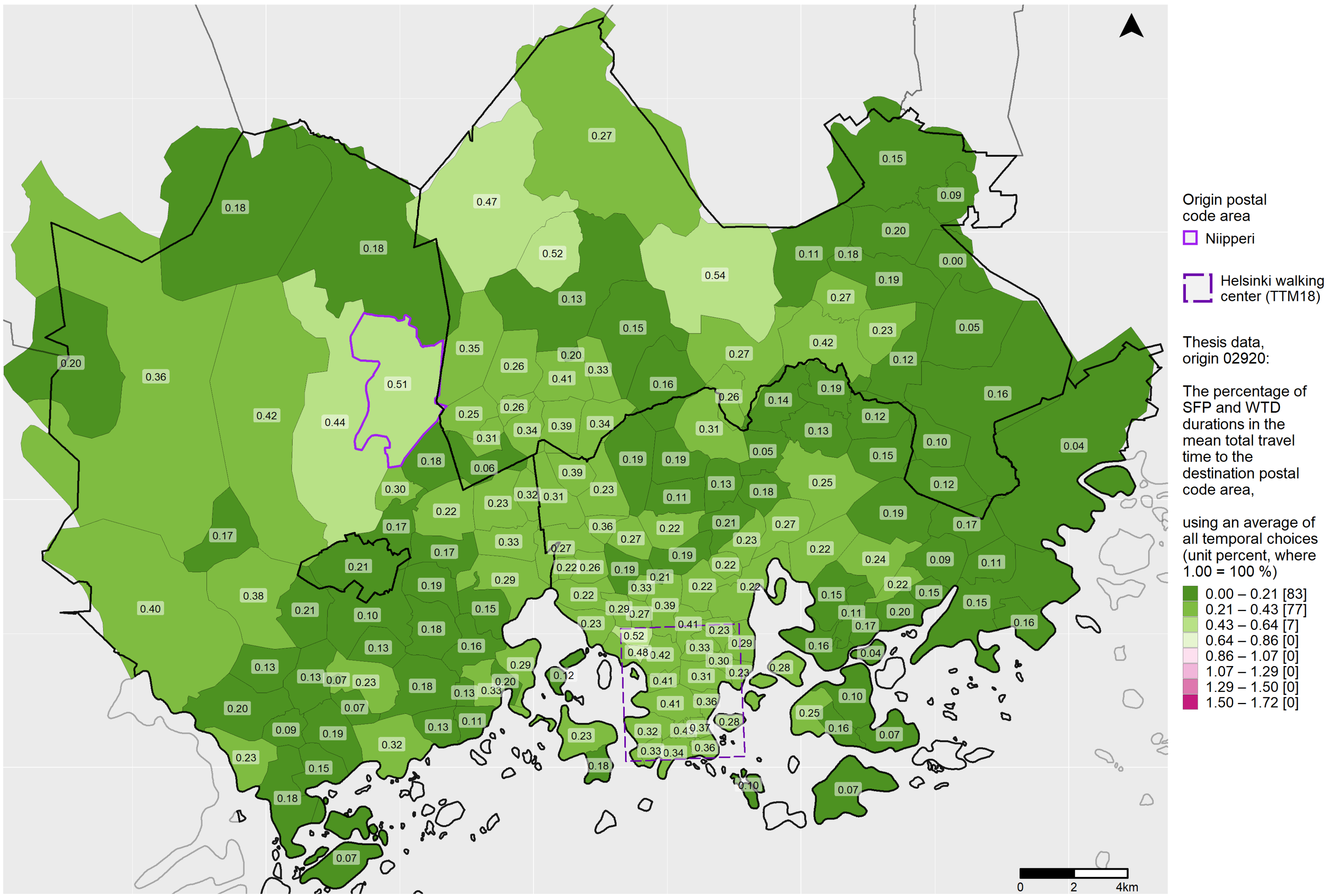


Figure 42. The parking process proportion in the total travel chain, using all temporal values, starting from 02920 Niipperi.

5 Discussion

5.1 Measuring survey success

To my knowledge, this is the first parking study of any spatial and temporal resolution in Helsinki Capital Region. Consequently, actual data about parking process durations and parking behaviour in a spatial context in the area has been non-existent. This study shows that there are spatial differences in the time that it takes to park one's car in the Helsinki Capital Region. This was the hypothesis going in to the research, as it seemed to be a clear oversimplification on the part of Helsinki Region Travel Time Matrix to assume that one static value would represent the parking process length in the functionally diverse urban capital region. The thesis survey was designed with practical experience on urban parking, with much of the collected data providing statistically significant explanation why there are spatial differences between areas. An additional hypothesis, in which the parking process was predicted to be significant share of the total travel time in a travel chain, was confirmed. The proportion of the parking process is significant all over Helsinki Capital Region.

Long searching for parking was found especially in the inner city of Helsinki, in 02230 Matinkylä, Espoo, and in 01300 Tikkurila and 01530 Veromiehenkylä, Vantaa. Long walking times were spread around the Helsinki Capital Region more evenly than parking times. In particular, inner Helsinki was again found to have long walking times, but so were 00570 Kulosaari, 00700 Malmi and 00590 Kaitalahti (see appendices I and II for locations of these areas). In Espoo, the long walking times concentrated in 02100 Tapiola and maybe surprisingly, in 02820 Nupuri-Nuuksio and in 02780 Kauklahti. In Vantaa, a wedge-like area from Tikkurila to 01760 Seutula formed the areas with long walking times in Vantaa. It is useful to remember, however, that in general postal code areas in Espoo and Vantaa have significantly smaller amount of responses compared to Helsinki. As many postal code areas inside the inner Helsinki received a hundred or more responses, Nupuri-Nuuksio and Kauklahti received 11 and 10 responses, respectively. Before the survey data collection, a more spatially even distribution of responses was expected. It now seems, that either A) most of the private car traffic concentrates toward the services and venues in Helsinki, with much less activity in the other municipalities, or, B) most of the survey respondents live in Helsinki and mostly only drive within the boundaries of their home municipality. The fact that the majority of the publicity work for the survey was done in Facebook groups based in Helsinki supports the latter assumption.

Parking times and walking times vary substantially between postal code areas and this study determined that the variation can be explained with the location inside the cities (explanatory variable `subdiv`), at what time of the day one attempted to find a parking spot (`timeofday`), and what type of parking spot was used (`parkspot`). Perhaps the strongest explanation to spatial differences could be found from zones of urban structure (`ykr_zone`). The familiarity of the parking postal code area (`likert`) did not necessarily mean shorter parking search times in the study area. This finding is in line with the literature (Thompson and Richardson 1998; Teng et al. 2002).

This study shows that the significance of the parking process in complete travel chains in the Helsinki Capital Region is substantial. According to the results, the Helsinki Region Travel Time Matrix's use of the parking search time value from Kalenoja and Häyrynen (2003) and walking time values from Kurri and Laakso (2002) are underestimations. In most postal code areas close to the origin postal code area, the parking process proportion is effortlessly over 20 % of the total travel chain duration, and 50 % is certainly not unheard of. When comparing proportions of the *Travel Time Matrix* driving time segments and the thesis parking process results (column name *thesis_x_pct* in figure 19), it may be observed that travel chains where the parking process is longer than the driving time segment are not uncommon.

The survey successfully withstood accidental and intentional misuse. Using safeguards such as server side filtering of incoming data prevented possible attempts at mischief. Further in the workflow, the analysis Python script made sure the amount of questionable responses were at a minimum. The survey program front-end made a great effort to appear easy to use to prevent frustration and premature exiting. The extensive dataset collected during the survey research further indicates that low response rate is not a given in web surveys (limits of web surveys discussed in Salonen et al. (2014)). For survey respondent retention, short length, high intelligibility, and a fluid user experience must be kept a top priority.

During the data collection phase, over 50 comments regarding the thesis research survey were received on the social media platform Facebook. The comments offered little insights but a few highlights helped shine light on the shortcomings of the survey. Some comments verified my suspicions about potential problems I had in my mind already when programming the survey.

About a fifth of the comments contained a positive message. Some people found the survey well designed and others thought the research subject was interesting and topical. Some more than fifth of the comments were critical of the survey. A few people stated that they felt intimidated by the breadth of the task asked of them. Suggestions were offered to make the survey seem less like a chore: inquire only a few postal code areas per person, or shorten the two year timeframe respondents were supposed to think back on. However, there is support for long survey timespans in the literature: short survey periods may not capture less frequent travel (Mokhtarian and Chen 2004). It must be noted that the long timespan may have been counter-productive for the survey research, as discussed by Brown (2012). A handful of individuals felt that they were not given the tools to convey the experience that some areas in Helsinki Capital Area are sometimes in dire shortage of parking places, but othertimes the same areas are easy to park in. Areas with large event venues were brought up. Two comments talked about parking events that do not happen because of perceivedly bad parking opportunities or failed parking events. These circumstances could function as foundations for later research. Some individuals had problems comprehending the user interface or encountered technical problems. These cases were difficult to deal with as there was no way of knowing if respondents had really read the survey instructions or if the situation was a genuine issue in the programming of the survey. As a matter of fact, I received a comment which declared the survey non-relevant, as they had misunderstood that the survey is only available in English. Finally, one person conveyed the disappointment of the unavailability of Swedish language in the survey.

In a particularly useful comment, a person noted that it was not possible to create records for Vantaa's Nikinmäki. This prominent issue had stayed hidden from me until the survey was in production and Nikinmäki's exclusion may have costed me some data about Vantaa. In an other comment, a person brought forward their confusion about the mainline instruction that parking made in personally reserved parking places should not be reported in the survey, but at the same time one of the parking place types in the variable `parkspot` was *Private or reserved parking spot*. This comment made me aware of this wording issue and increased my alertness for other issues such as this.

More than a fifth of the comments contained a message of dissatisfaction about the current state of private car parking in the Helsinki Capital Region. In some cases, the invitation to participate in the research was met with blunt retorts without any connections to the survey. A person said that they could not receive visitors because of the situation with the parking spaces. Another said that parking in the center is starting to resemble an utopian dream, while a third person disclosed that they had abandoned all ideas of parking in the center since 2013. In these messages, the expensiveness and difficulty of parking in the center of Helsinki was lamented. In this research, the center was indeed found to contain some of the longest times to search for parking but it was seemingly forgotten by these persons that the survey was interested in a vast expanse of areas beside the center of Helsinki. These comments of vexation lead me to believe that at least some of the anomalous `parktime` and `walktime` values that reached the maximum value 99 were made in protest.

The survey comments received on Facebook painted an interesting picture of at least a few types of potential survey respondents. Even though most people stayed quiet and participated, there are lessons to be learned in these voiced opinions. For example, it became ever clearer that the user experience has to be a top priority. If the survey landing view looks intimidating, respondents may be lost. If there is too much to read in the beginning, respondents are probably lost. Finally, the potential respondents have zero patience for failing programming. As can be viewed from the *visitors* dataset, a majority of survey visitors stopped by for only a single time. Valuable data is lost if survey administrator can't respond to these demands. I consider the thesis survey a success as it gathered a considerable amount of comments and likes in the Facebook groups, the main channel of promotion, and gathered a large amount of valid data. Even if only ten seconds was spent with each data row, the combined time it would take to fill out the survey 5183 times totals in nearly 15 hours.

5.2 Survey and analysis uncertainties

A major source of uncertainty in this study stems from the design of the survey research. The phrasing of questions, available answering options to the questions, and the technical design are of major relevance. The research survey application contained an extensive help functionality to instruct respondents how to respond with valid answers. When it was decided that the survey should not inquire specific parking events, but a general experience in a predetermined timeframe, a factor of uncertainty was accepted in the sense that as parking habits were disconnected from specific time and place, respondents were given leeway in question interpretation. Despite efforts to communicate essential information to respondents, it is not possible to be sure that everyone understood what it meant when respondents were asked to report about their parking experiences *usually*. Respondents were supposed to only think back two years to weed out estimations about parking infrastructure that potentially no longer exists or has changed considerably. A question with no definitive answer can be asked about the significance of rapid construction in different parts of the Helsinki Capital Region. How much weight the large shifting construction sites of 00220 Jätkäsaari and 01700 Kivistö bear in the minds of the respondents? In addition, as the survey was provided in both Finnish and English languages, there is a possibility for differently understood questions based on the language used.

Regarding the postal code areas dataset, a source of additional uncertainty rises from the fact that postal code areas were used as the main spatial unit. The benefit was streamlined survey design and lower possibility for data collection failure as the study would have needed a very large amount of responses to be valid. However, using the postal code areas obscures the actual hotspots of parking activity in the Helsinki Capital Region. We are now unable to see if responses have spread out to whole postal code areas or concentrated on a few popular activity locations. Additionally, using postal code areas forces this study to use averages when comparing the thesis survey data and Helsinki Region Travel Time Matrix 2018 data. For instance, this means that the southern road connected islands of 02380 Suvisaaristo are "as close to" 02360 Espoonlahti as the northern part of Suvisaaristo is.

A manner of uncertainty stems from the possibility to answer to `parktime` and `walktime` questions with implausibly large values, such as with the maximum of 99 minutes, i.e., it took the respondent 99 minutes to walk from their car to the final destination of their travel chain. In this thesis, the issue was solved by simply excluding all `parktime` and `walktime` values over 59 minutes, an entirely arbitrarily chosen value. Although these high values are improbable and their exclusion relatively inconsequential, some respondents may have reported real parking experiences which have now been left unexamined. Through feedback received in Facebook, I am able to deduce that some of the large values, especially the ones reporting 99 for both `parktime` and `walktime`, may have been made as protest to signify that parking is not possible or is highly unpleasant in the postal code areas concerned.

Regarding the single-answer questions in the survey, such as *What kind of parking spot do you* *usually take in this postal code area?*, several of the available choices were problematic. Especially problematic is the choice *Private or reserved*, which was meant to describe a parking space that is located, for example, in the parking lot owned by one's employer where one has a right to park but no specific reserved spot. Without browsing the survey help, it is entirely possible to believe this choice can be used for reporting home yard parking, an unwanted result. The choice *Other* could, too, potentially be used to report parking at home. If these problematic `parkspot` answer scenarios happened, they are of relatively minimal consequence as 284 responses reported *Private or reserved*, and only 39 responses reported *Other*.

The thesis survey experienced an issue originating from postal code areas dataset that was only revealed after the survey had gone public. The postal code area boundaries do not completely follow the boundaries of municipalities. Nevertheless, the postal code areas dataset considers each postal code area to belong in a single municipality, leading to the situation where the neighborhood of Nikinmäki, Vantaa was completely excluded from the research (missing Nikinmäki in figure 4, northeastern Vantaa. See also appendices I and II). In surface area more than a half of the postal code area 01490 Nikinmäki is indeed located in the municipality of Sipoo, but the majority of urban activity in that postal code area is located in Vantaa. Regardless, this research lost some responses because of this oversight.

Even though the survey application provided tools to locate places and addresses accurately, it cannot be ruled out that some respondents could have sent answers about a postal code area when they meant to send those answers about a neighboring postal code. Furthermore, the open numeric fields for `parktime` and `walktime` introduce a source of distortion in that people seemed to prefer reporting easy, common amounts of time, such as five minutes, ten minutes, or twenty minutes. This trend can be viewed in the *records* analysis application histograms and in the figures 26 and 27. Behaviour such as this is to be expected when people are required to make estimations of past amounts of time. Thus, the variables `parktime` and `walktime` as well as the end results in the travel time comparison application have to be treated in same fashion. One additional matter to consider is the fallibility of respondents' memory. To what extent we can assume the survey results are from the correct time period, or location? According to Brown (2012), however, there is a relation between respondent's familiarity with the area of study and spatial accuracy.

The calculation methods for some of the variables in the survey analysis application is an additional matter for consideration. In the case of explanatory variables `artificial` and `ykr_zone`, a rather arbitrary approach was used for the originally continuous data. The variable `artificial`, was simplified from a percentage value 0–100 % to five Jenks natural breaks classes. A source of uncertainty in `artificial` is the naming of these classes, which was based on the best practices by Brown (2010), but ultimately, the naming was subjectively decided. Additionally, it could be considered an oversimplification to say that, for example, 40 % of artificial surface in a postal code area means that it can be characterised as *Some built*. The variable `ykr_zone` was subjected to arguably more drastic simplification. In the original *YKR zones* data, each postal code area could contain as much as six different classes of urban structure and the leftover classes, which I have designated *novalue* in this thesis. It, too, can be considered an oversimplification to choose only a singular largest zone of urban structure in each postal code area, causing some structurally diverse postal code areas, like 02270 Espoon keskus, to appear as *novalue*, even when the area consists of only 28 % of *novalue* and contains four actual classes of *YKR zones* data. For a future reference in similar contexts, it could be an informed decision to set specific conditions to minimise the presence of *novalue*.

The survey data processing script written in Python has a feature to detect duplicate responses in the survey results. Using this tool, it is possible to conclude that 19 IP addresses sent responses that contained responses from same postal code areas. It can be discussed what has happened in these cases but no definite answer can be drawn and these cases can not be labeled as unwanted duplicates. It is possible that people sharing an internet connection may have legitimately sent their own responses, and indeed, in these cases the individual questions should have varying answers. The tool detects if the suspect IP addresses have identical answers in the individual questions. This could possibly indicate an attempt to influence the results of the survey. Mostly the suspect IP addresses have none or some identical answers, with a few IP addresses having the maximum of five identical answers. If the timestamps of these identical answers are close to each other, we can deduce that these are real duplicates. Identical responses were sent from four IP addresses and these identical responses were indeed sent only minutes apart. In the case of one separate IP address, the postal code 00790 Viikki was entered a total of nine times. It is possible, as no identically answered questions were detected in this case, that these responses originated from a public network such as a campus of the University of Helsinki. With no definite way to answer the questions regarding the duplicate responses, these suspected responses were included in the survey results. Furthermore, the 19 suspect IP address codes is ultimately a negligible fraction of the total visit count.

5.3 Avenues for future research

The research survey carried out for this thesis can be considered a success with the total of 5579 visits to the survey website and the 5183 received data rows. The collected datasets *visitors* and *records* are voluminous troves of data and this study observed them from a carefully defined angle leaving many other approach vectors unexplored. Combining the collected datasets with pre-existing spatial datasets and other sources of data could potentially lead to new findings about the parking habits of people that answered to the survey. In particular, the dataset *visitors* was used in a superficial manner because of the arrangement of research questions and the survey's statement of privacy, which promised minimal use of personal data. In another context, the respondent behaviour could be used to find additional patterns in the *records* dataset. Considering extended statistical analysis, it is possible to test a countless combination of explanatory variables against the response variables with equally many freely chosen spatial extents with exclusion of municipalities or municipality subdivisions. Much of this additional analysis can be carried out at any time with the analysis applications programmed for this thesis.

In regard to the travel time comparison application programmed for this thesis, it would be useful to calculate median and variance of all values to provide further insight into the shape of the data and avoid extreme values gaining prominence in the spatial analysis of the parking process.

In a future travel time study adhering to the door-to-door approach, the concepts of origin and the final destination of the travel chain could be taken a step further. Instead of assigning the origins and destinations of travel chains in a two dimensional plane, more detail could be achieved with the addition of the third dimension. Many cities, including Helsinki, Espoo, and Vantaa have already released their respective three dimensional city models for residents and developers alike (Helsingin kaupungin kaupunginkanslia 2020; Espoon kaupungin tekninen ja ympäristötoimi 2018; Vantaan kaupunki 2018). In addition to providing exquisitely detailed visualisation, these models can be used in scientific research. For instance, Willenborg et al. (2018) integrated two types of three dimensional models of Helsinki for solar energy potential analysis. In a parking process study, these advanced city models could be used to place parking events inside multi-storied garages, from where walking times to a final destination in a multi-storey department store could be mapped in three dimensions for added temporal accuracy.

Aside from the basic area identifying data, the postal code areas dataset includes dozens of columns of demographic data for each postal code area in Finland. The study did not make use of these components of the dataset. Employing this attribute data in parking research could bear deeper understanding about parking behaviour in the Helsinki Capital Region. One could, for example, attempt to find links between postal code areas of many work places and long parking times, or areas with high amount of buildings and long walking times.

HRI has released a spatial dataset which contains the locations of parking spots in Southern Helsinki, in a total of 13 postal code areas (Helsingin kaupunkiympäristön toimiala 2017). HRI states that the material contains errors and is not actively supported. If this dataset encompassed a larger share of the Helsinki Capital Region and more resources was put into it, the parking process research could descend from the abstract level for a more grounded take on parking private cars in urban setting and the challenges it involves. The amount of parking spaces, even if it would only be an estimate, would shed an informative light into the possible connection of cruising for parking and parking places.

5.4 Conclusions

In this thesis, parking of private cars was studied with a Public Participation Geographic Information System (PPGIS) survey in the Helsinki Capital Region, Finland. Adhering to the concept of *spatial accessibility*, this study aimed to find out if there spatial differences in the time it takes to park one's car and walk to one's destination in the study area. In the case differences would be found, the study aimed to explain the differences.

The analysis of the survey data showed that there are substantial differences in parking search durations and walking time duration and between postal code areas of the Helsinki Capital Region. Through the collection of additional explanatory data, such as the time of day of the parking, a glimpse to the multifaceted parking search behaviour was made possible.

Utilising the data obtained through the survey, the significance of the parking process in the total travel chain could be determined. The integration of the survey data and the Helsinki Region Travel Time Matrix dataset by Digital Geography Lab of the University of Helsinki showed that the proportion of the parking process duration can be a half of the total travel chain duration, and in many cases, more.

With the results of this thesis, more sophisticated routing models in the Helsinki Capital Region become attainable. Until now, only rudimentary estimations of the parking process length in the study area have been available as parking surveys such as the one conducted in this thesis have not been available. Employing better route planning algorithms can help cities combat the complex set of problems that arise from the mismatch between parking intentions of the motorists and available supply of parking places. The integration of realistic parking process data into route analysis may help divert the focus of urban transport planning away from mobility and more into the field of accessibility, increasing the desirability of alternative, often more sustainable, travel mode choices. It has been shown in the literature that there is will for this change.

The source code repositories for *records*, *visitors*, *comparison* analysis applications are available at GitHub:

– https://github.com/sampoves/thesis-analysis-shinyapps,
– https://github.com/sampoves/thesis-visitors-shinyapps, and
– https://github.com/sampoves/thesis-comparison-shinyapps.

The applications may be viewed on shinyapps.io:

– https://sampoves.shinyapps.io/analysis,
– https://sampoves.shinyapps.io/visitors, and
– https://sampoves.shinyapps.io/comparison.

6 References

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Appendix I

Appendix I. PAAVO postal code areas in Helsinki Capital Region.

Postal code	Name in Finnish	Name in Swedish	Municipality
00100	Helsinki Keskusta - Etu-Töölö	Helsingfors centrum - Främre Tölö	Helsinki
00120	Punavuori	Rödbergen	Helsinki
00130	Kaartinkaupunki	Gardesstaden	Helsinki
00140	Kaivopuisto - Ullanlinna	Brunnsparken - Ulrikasborg	Helsinki
00150	Eira - Hernesaari	Eira - Ärtholmen	Helsinki
00160	Katajanokka	Skatudden	Helsinki
00170	Kruununhaka	Kronohagen	Helsinki
00180	Kamppi - Ruoholahti	Kampen - Gräsviken	Helsinki
00190	Suomenlinna	Sveaborg	Helsinki
00200	Lauttasaari	Drumsö	Helsinki
00210	Vattuniemi	Hallonnäs	Helsinki
00220	Jätkäsaari	Busholmen	Helsinki
00230	Ilmala	Ilmala	Helsinki
00240	Länsi-Pasila	Västra Böle	Helsinki
00250	Taka-Töölö	Bortre Tölö	Helsinki
00260	Keski-Töölö	Mellersta Tölö	Helsinki
00270	Pohjois-Meilahti	Norra Mejlans	Helsinki
00280	Ruskeasuo	Brunakärr	Helsinki
00290	Meilahden sairaala-alue	Mejlans sjukhusområde	Helsinki
00300	Pikku Huopalahti	Lillhoplax	Helsinki
00310	Kivihaka	Stenhagen	Helsinki
00320	Etelä-Haaga	Södra Haga	Helsinki
00330	Munkkiniemi	Munksnäs	Helsinki
00340	Kuusisaari-Lehtisaari	Granö-Lövö	Helsinki
00350	Munkkivuori-Niemenmäki	Munkshöjden-Näshöjden	Helsinki
00360	Pajamäki	Smedjebacka	Helsinki
00370	Reimarla	Reimars	Helsinki

Appendix I. PAAVO postal code areas, continued from previous pages.

Postal code	Name in Finnish	Name in Swedish	Municipality
00380	Pitäjänmäen teollisuusalue	Sockenbacka industriområde	Helsinki
00390	Konala	Kånala	Helsinki
00400	Pohjois-Haaga	Norra Haga	Helsinki
00410	Malminkartano	Malmgård	Helsinki
00420	Kannelmäki	Gamlas	Helsinki
00430	Maununneva	Magnuskärr	Helsinki
00440	Lassila	Lassas	Helsinki
00500	Sörnäinen	Sörnäs	Helsinki
00510	Etu-Vallila - Alppila	Främre Vallgård - Alphyddan	Helsinki
00520	Itä-Pasila	Östra Böle	Helsinki
00530	Kallio	Berghäll	Helsinki
00540	Kalasatama	Fiskhamnen	Helsinki
00550	Vallila	Vallgård	Helsinki
00560	Toukola-Vanhakaupunki	Majstad-Gammelstad	Helsinki
00570	Kulosaari	Brändö	Helsinki
00580	Verkkosaari	Nätholmen	Helsinki
00590	Kaitalahti	Hålvik	Helsinki
00600	Koskela-Helsinki	Forsby-Helsingfors	Helsinki
00610	Käpylä	Kottby	Helsinki
00620	Metsälä-Etelä-Oulunkylä	Krämertsskog-Södra Åggelby	Helsinki
00630	Maunula-Suursuo	Månsas-Storkärr	Helsinki
00640	Oulunkylä-Patola	Åggelby-Dammen	Helsinki
00650	Veräjämäki	Grindbacka	Helsinki
00660	Länsi-Pakila	Västra Baggböle	Helsinki
00670	Paloheinä	Svedängen	Helsinki
00680	Itä-Pakila	Östra Baggböle	Helsinki
00690	Tuomarinkylä-Torpparinmäki	Domarby-Torparbacken	Helsinki
00700	Malmi	Malm	Helsinki
00710	Pihlajamäki	Rönnbacka	Helsinki
00720	Pukinmäki-Savela	Bocksbacka-Lerstrand	Helsinki

Appendix I. PAAVO postal code areas, continued from previous pages.

Postal code	Name in Finnish	Name in Swedish	Municipality
00730	Tapanila	Mosabacka	Helsinki
00740	Siltamäki	Brobacka	Helsinki
00750	Puistola	Parkstad	Helsinki
00760	Suurmetsä	Storskog	Helsinki
00770	Jakomäki - Alppikylä	Jakobacka - Alpbyn	Helsinki
00780	Tapaninvainio	Staffansslätten	Helsinki
00790	Viikki	Vik	Helsinki
00800	Länsi-Herttoniemi	Västra Hertonäs	Helsinki
00810	Herttoniemi	Hertonäs	Helsinki
00820	Roihuvuori	Kasberget	Helsinki
00830	Tammisalo	Tammelund	Helsinki
00840	Laajasalo	Degerö	Helsinki
00850	Jollas	Jollas	Helsinki
00860	Santahamina	Sandhamn	Helsinki
00870	Etelä-Laajasalo	Södra Degerö	Helsinki
00880	Roihupellon teollisuusalue	Kasåkerns industriområde	Helsinki
00890	Itäsalmi	Östersundom	Helsinki
00900	Puotinharju	Botbyhöjden	Helsinki
00910	Puotila	Botby gård	Helsinki
00920	Myllypuro	Kvarnbäcken	Helsinki
00930	Itäkeskus-Marjaniemi	Östra centrum-Marudd	Helsinki
00940	Kontula - Vesala	Gårdsbacka - Ärvings	Helsinki
00950	Vartioharju	Botbyåsen	Helsinki
00960	Pohjois-Vuosaari	Norra Nordsjö	Helsinki
00970	Mellunmäki	Mellungsbacka	Helsinki
00980	Etelä-Vuosaari	Södra Nordsjö	Helsinki
00990	Aurinkolahti	Solvik	Helsinki
01200	Hakunila	Håkansböle	Vantaa
01230	Vaarala	Fagersta	Vantaa
01260	Itä-Hakkila	Östra Haxböle	Vantaa

Appendix I. PAAVO postal code areas, continued from previous pages.

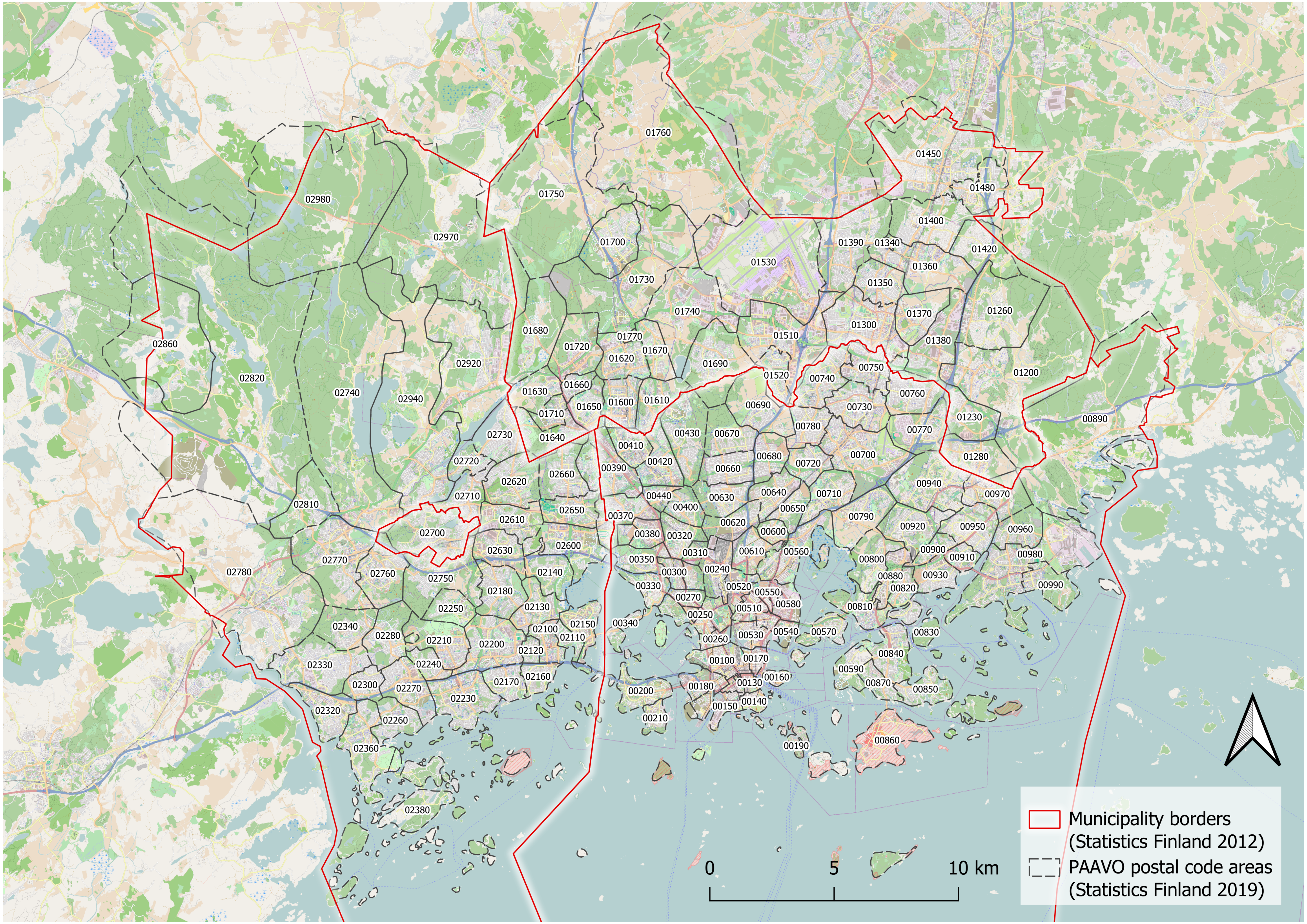
Postal code	Name in Finnish	Name in Swedish	Municipality
01280	Länsimäki	Västerkulla	Vantaa
01300	Tikkurila	Dickursby	Vantaa
01340	Leinelä	Lejle	Vantaa
01350	Hiekkaharju	Sandkulla	Vantaa
01360	Koivukylä-Havukoski	Björkby-Havukoski	Vantaa
01370	Jokiniemi	Ånäs	Vantaa
01380	Kuusikko-Hakkila	Sexan-Håkansböle	Vantaa
01390	Ruskeasanta-Ilola	Rödsand-Gladas	Vantaa
01400	Rekola	Räckhals	Vantaa
01420	Päiväkumpu	Lövkulla	Vantaa
01450	Korso	Korso	Vantaa
01480	Mikkola	Mikkola	Vantaa
01510	Kirkonkylä-Veromäki	Kyrkoby-Skattbacka	Vantaa
01520	Tammisto	Rosendal	Vantaa
01530	Veromiehenkylä	Skattmansby	Vantaa
01600	Myyrmäki	Myrbacka	Vantaa
01610	Kaivoksela	Gruvsta	Vantaa
01620	Martinlaakso	Mårtensdal	Vantaa
01630	Hämeenkylä	Tavastby	Vantaa
01640	Hämevaara	Tavastberga	Vantaa
01650	Vapaala	Friherrs	Vantaa
01660	Varisto	Varistorna	Vantaa
01670	Vantaanlaakso	Vandadalen	Vantaa
01680	Askisto	Askis	Vantaa
01690	Ylästö	Övitsböle	Vantaa
01700	Kivistö	Kivistö	Vantaa
01710	Pähkinärinne	Hasselbacken	Vantaa
01720	Petikko	Petikko	Vantaa
01730	Vantaanpuisto	Vandaparken	Vantaa
01740	Tuupakan teollisuusalue	Stubbacka industriområde	Vantaa

Appendix I. PAAVO postal code areas, continued from previous pages.

Postal code	Name in Finnish	Name in Swedish	Municipality
01750	Keimola	Käinby	Vantaa
01760	Seutula	Sjöskog	Vantaa
01770	Martinlaakson teollisuusalue	Mårtensdals industriområde	Vantaa
02100	Tapiola	Hagalund	Espoo
02110	Otsolahti	Björnviken	Espoo
02120	Länsikorkee-Suvikumpu	Västerhöjden-Solhöjden	Espoo
02130	Pohjois-Tapiola	Norra Hagalund	Espoo
02140	Laajalahti	Bredvik	Espoo
02150	Otaniemi	Otnäs	Espoo
02160	Westend	Westend	Espoo
02170	Haukilahti	Gäddvik	Espoo
02180	Mankkaa	Mankans	Espoo
02200	Niittykumpu	Ängskulla	Espoo
02210	Olari	Olars	Espoo
02230	Matinkylä	Mattby	Espoo
02240	Friisilä	Frisans	Espoo
02250	Henttaa	Hemtans	Espoo
02260	Kaitaa	Kaitans	Espoo
02270	Finnoo-Eestinmalmi	Finno-Estmalmen	Espoo
02280	Malminmäki-Eestinlaakso	Malmbacka-Estdalen	Espoo
02290	Puolarmetsän sairaala	Bolarskogs sjukhus	Espoo
02300	Nöykkiönpuro	Nöykisbäcken	Espoo
02320	Espoonlahti	Esboviken	Espoo
02330	Saunalahti-Kattilalaakso	Bastvik-Kitteldalen	Espoo
02340	Latokaski	Ladusved	Espoo
02360	Soukka	Sökö	Espoo
02380	Suvisaaristo	Sommaröarna	Espoo
02600	Etelä-Leppävaara	Södra Alberga	Espoo
02610	Kilo	Kilo	Espoo
02620	Karakallio	Karabacka	Espoo

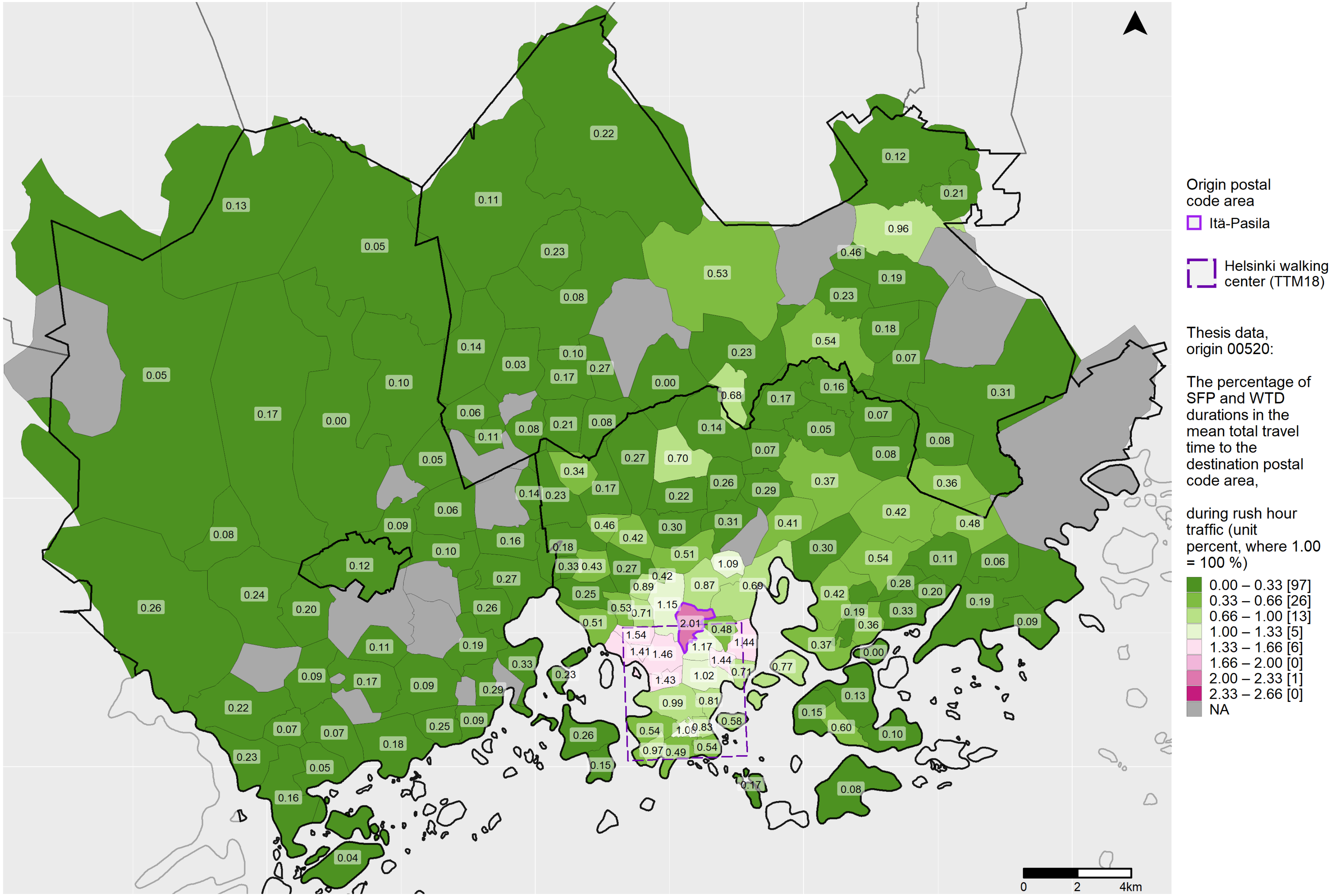
Appendix I. PAAVO postal code areas, continued from previous pages.

Postal code	Name in Finnish	Name in Swedish	Municipality
02630	Nihtisilta	Knektbro	Espoo
02650	Pohjois-Leppävaara	Norra Alberga	Espoo
02660	Lintuvaara	Fågelberga	Espoo
02680	Uusmäki	Nybacka	Espoo
02700	Kauniainen	Grankulla	Kauniainen
02710	Viherlaakso	Gröndal	Espoo
02720	Lähderanta	Källstrand	Espoo
02730	Jupperi	Jupper	Espoo
02740	Bemböle-Pakankylä	Bemböle-Backby	Espoo
02750	Sepänkylä-Kuurinniitty	Smedsby-Kurängen	Espoo
02760	Tuomarila-Suvela	Domsby-Södrik	Espoo
02770	Espoon Keskus	Esbo centrum	Espoo
02780	Kauklahti	Köklax	Espoo
02810	Gumböle-Karhusuo	Gumböle-Björnkärr	Espoo
02820	Nupuri-Nuuksio	Nupurböle-Noux	Espoo
02860	Siikajärvi	Siikajärvi	Espoo
02920	Niipperi	Nipert	Espoo
02940	Lippajärvi-Järvenperä	Klappträsk-Träskända	Espoo
02970	Kalajärvi	Kalajärvi	Espoo
02980	Lakisto	Lakisto	Espoo



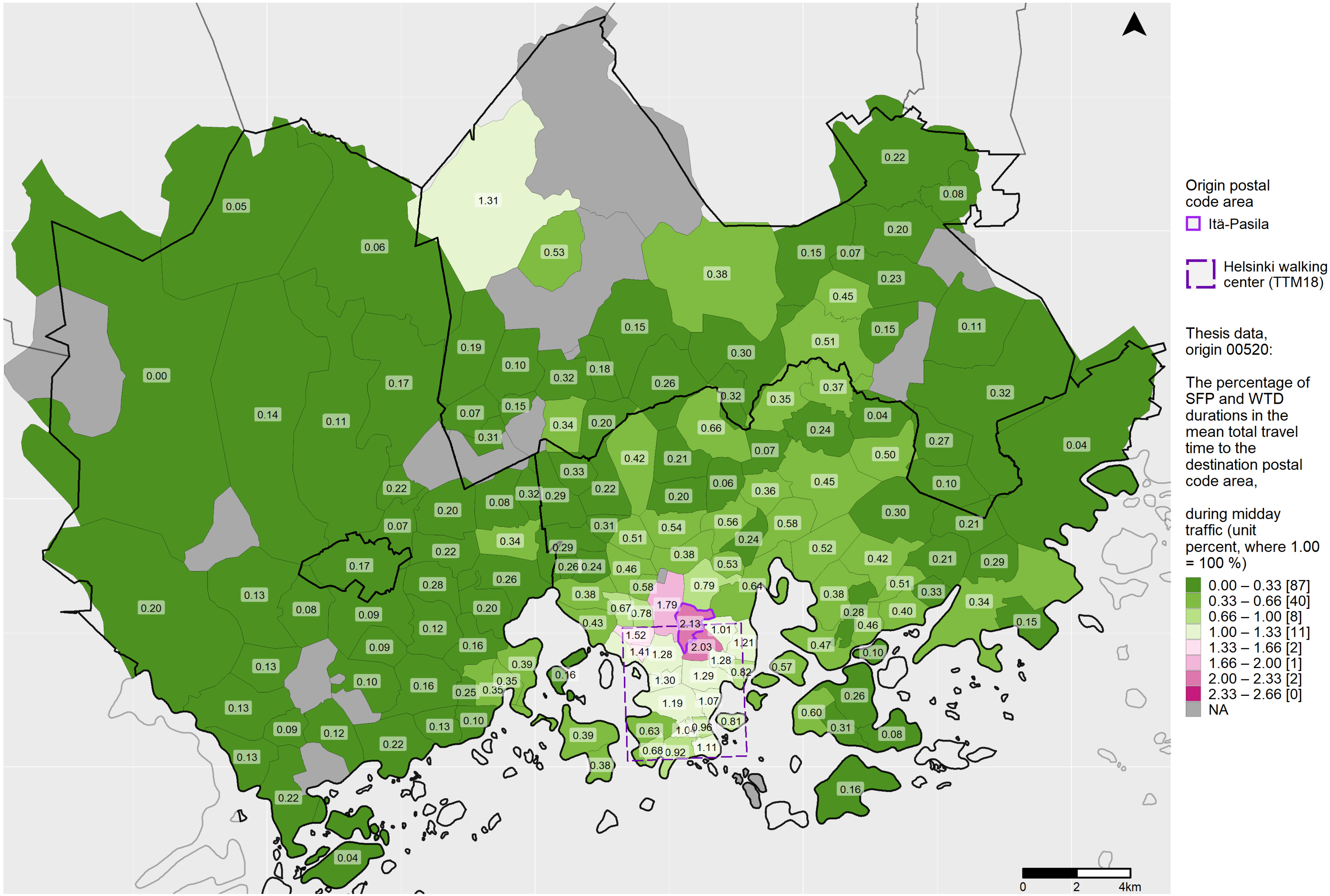
Appendix II. PAAVO postal code areas in the Helsinki Capital Region (OpenStreetMap contributors 2020).

Appendix III



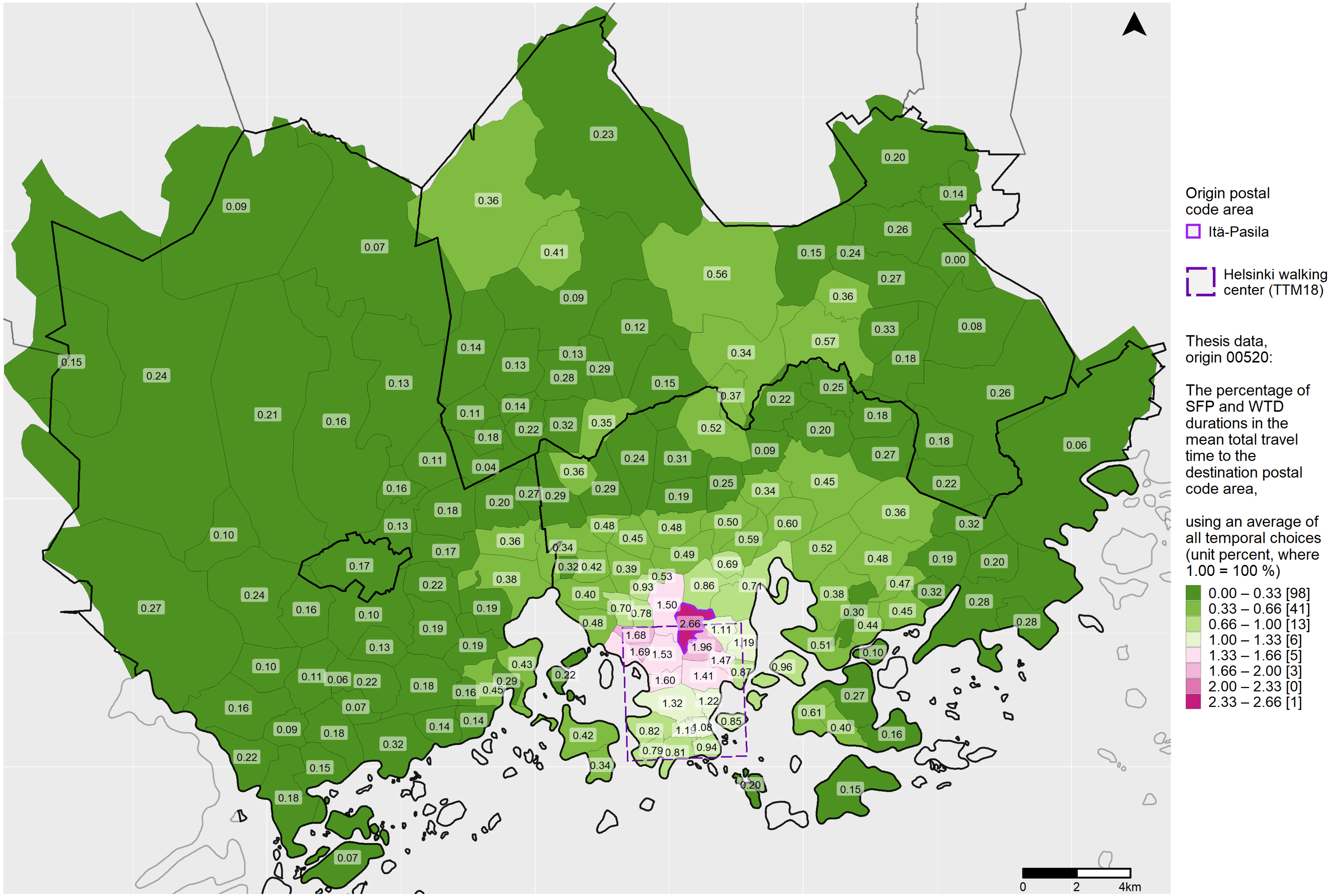
Appendix III. The parking process proportion in the total travel chain, in rush hour traffic, starting from 00520 Itä-Pasila. SFP stands for *searching for parking*, `parktime`, and WTD *walking to destination*, `walktime`. These are the components of the parking process in the *door-to-door approach*.

Appendix IV



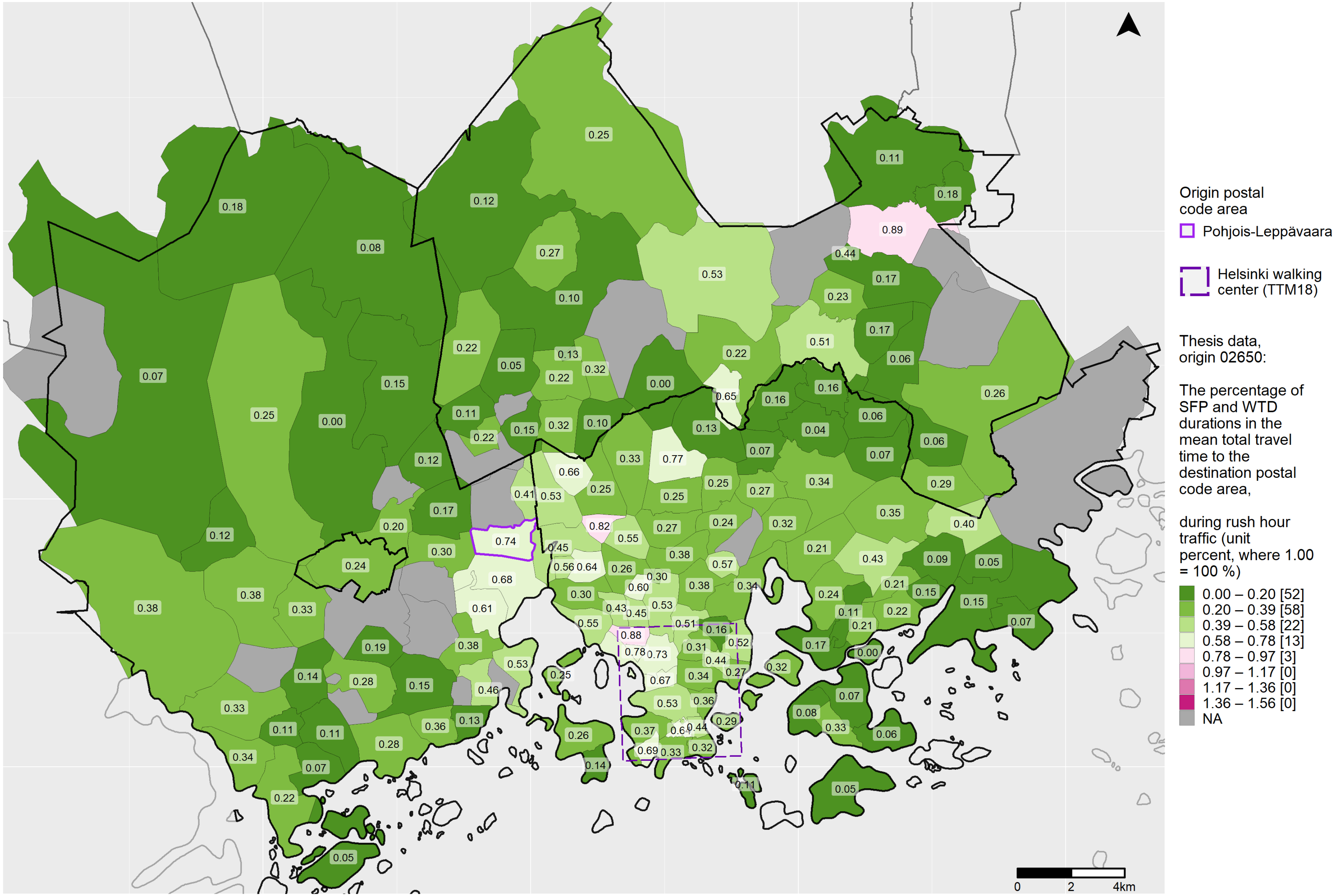
Appendix IV. The parking process proportion in the total travel chain, in midday traffic, starting from 00520 Itä-Pasila.

Appendix V



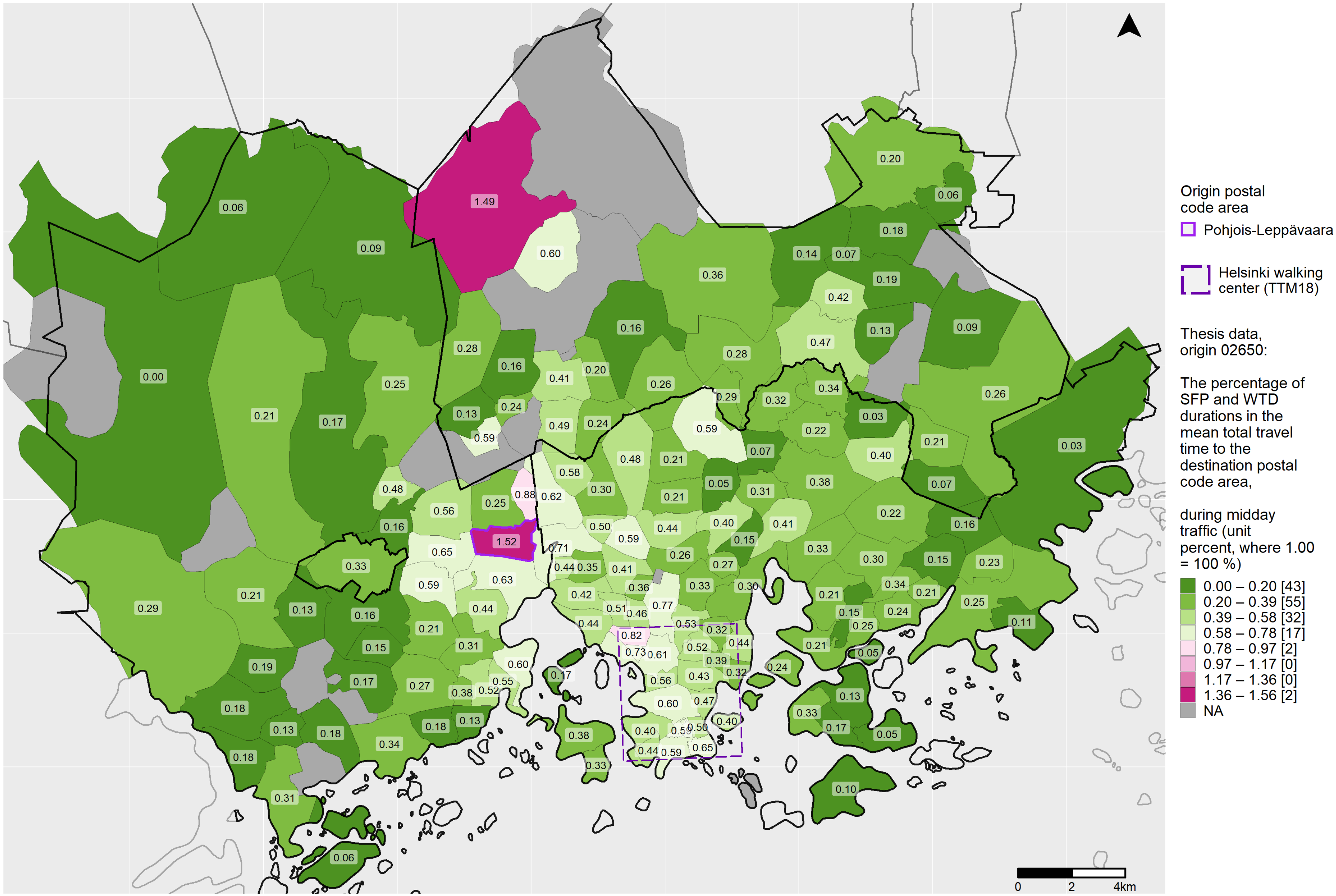
Appendix V. The parking process proportion in the total travel chain, using all temporal values, starting from 00520 Itä-Pasila.

Appendix VI



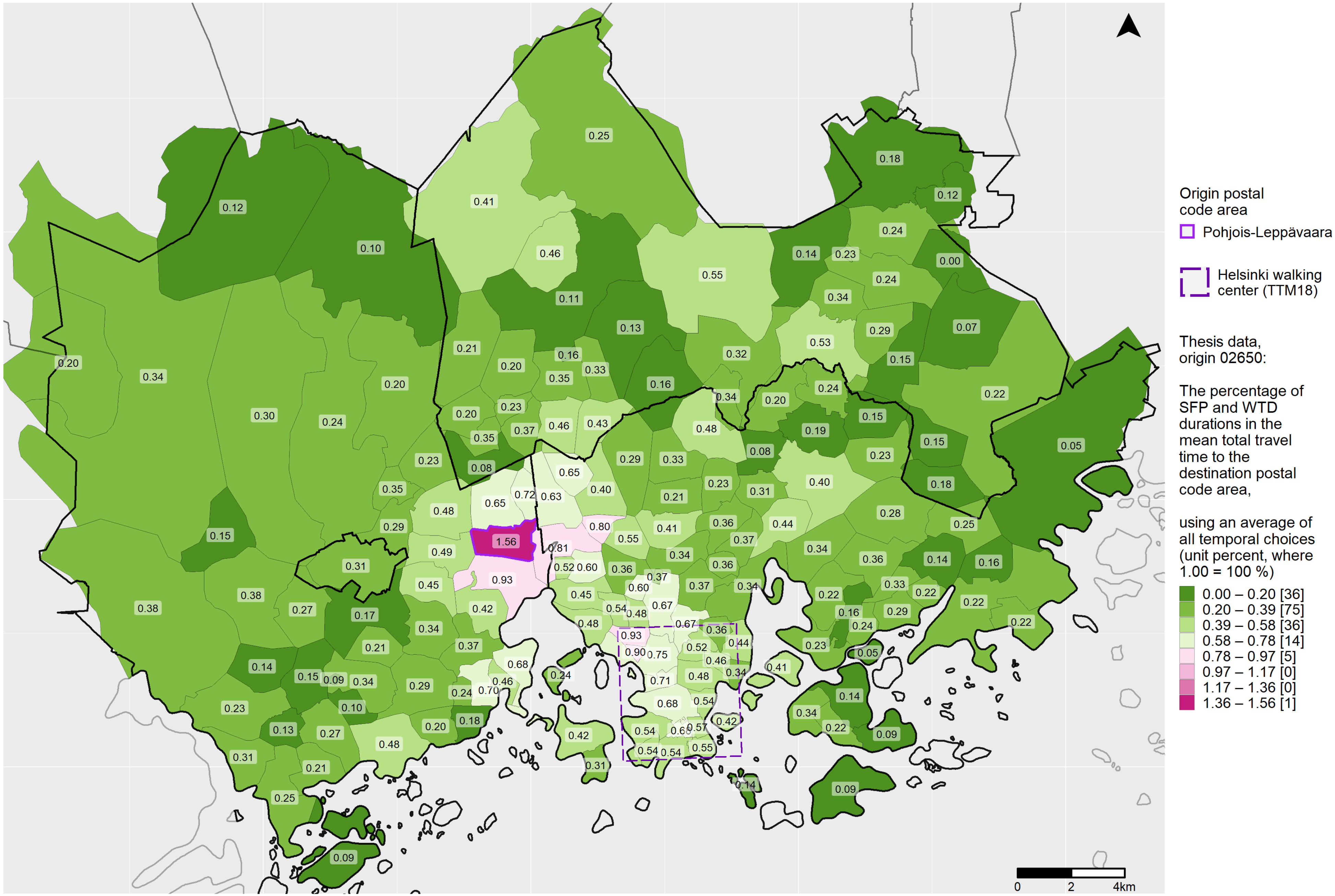
Appendix VI. The parking process proportion in the total travel chain, in rush hour traffic, starting from 02650 Pohjois-Leppävaara. SFP stands for *searching for parking*, `parktime`, and WTD *walking to destination*, `walktime`. These are the components of the parking process in the *door-to-door approach.*

Appendix VII



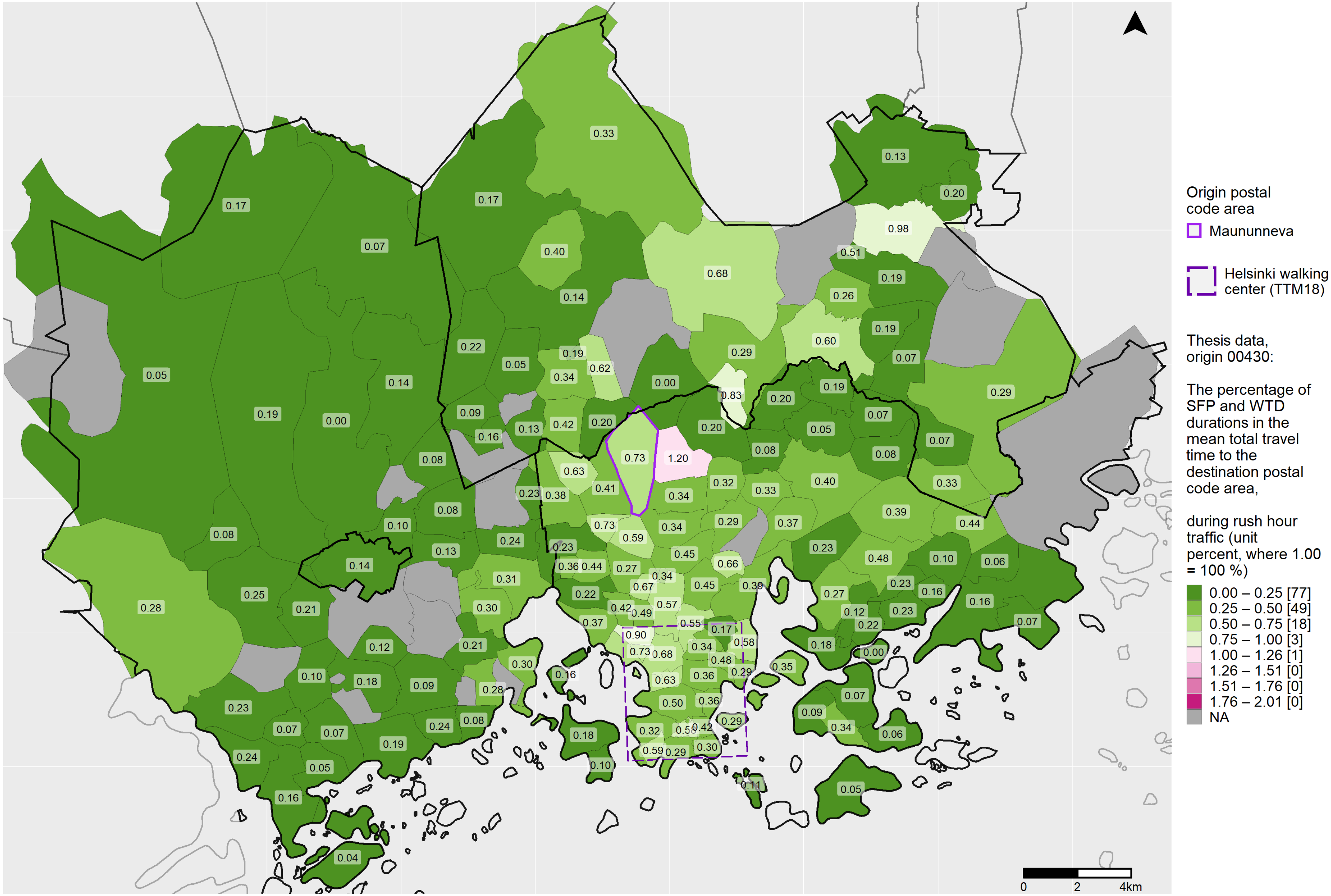
Appendix VII. The parking process proportion in the total travel chain, in midday traffic, starting from 02650 Pohjois-Leppävaara.

Appendix VIII



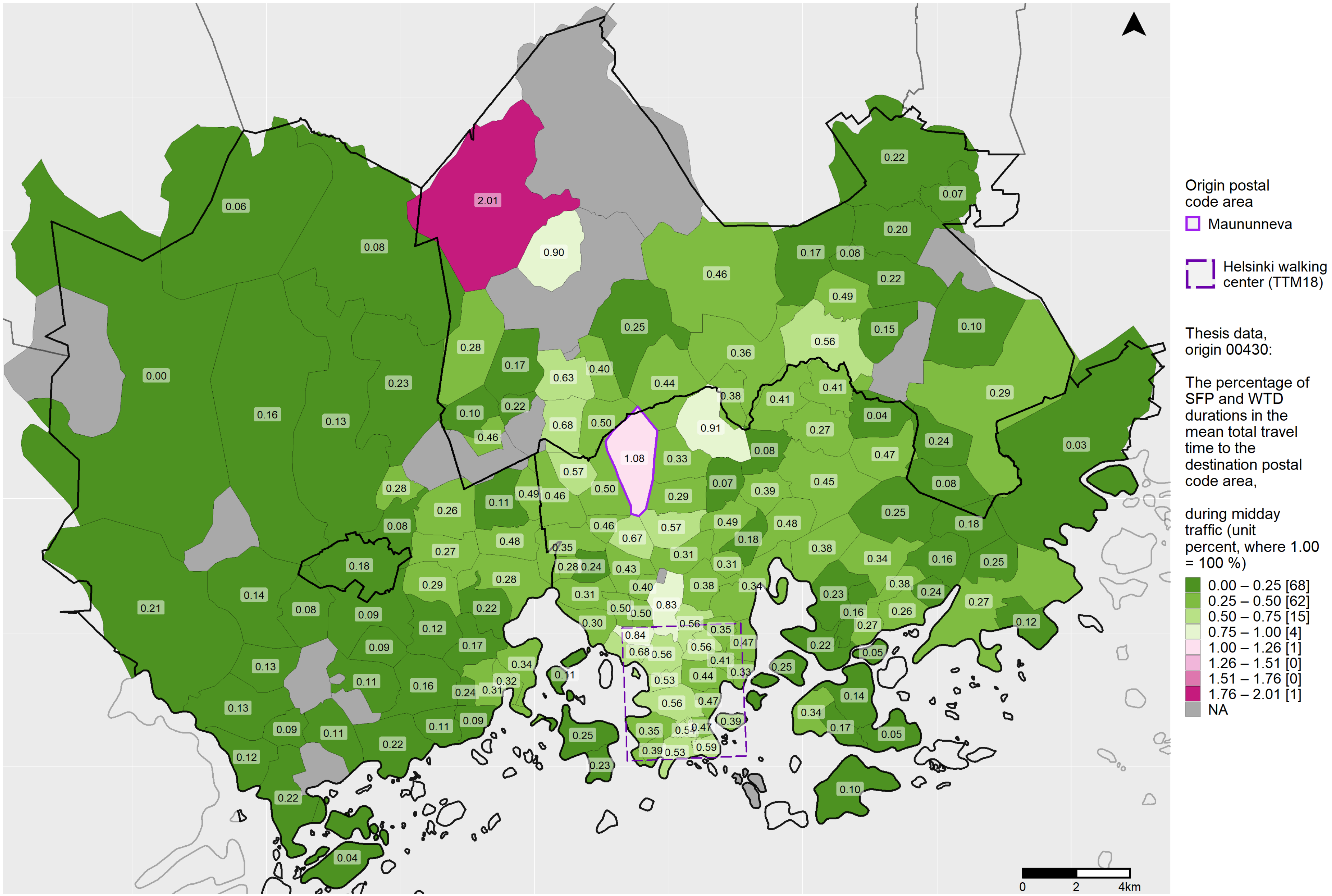
Appendix VIII. The parking process proportion in the total travel chain, using all temporal values, starting from 02650 Pohjois-Leppävaara.

Appendix IX



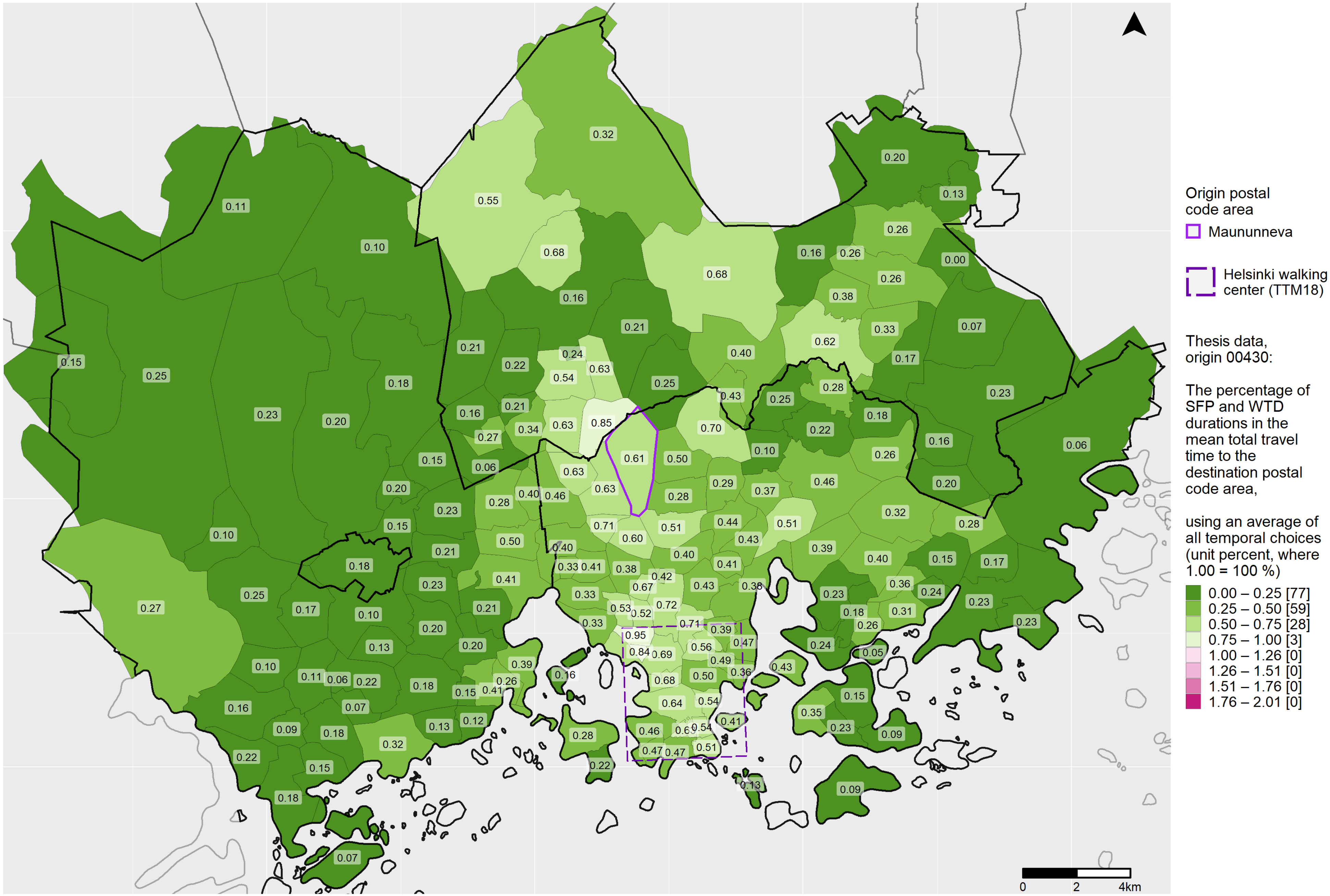
Appendix IX. The parking process proportion in the total travel chain, in rush hour traffic, starting from 00430 Maununneva. SFP stands for *searching for parking*, `parktime`, and WTD *walking to destination*, `walktime`. These are the components of the parking process in the *door-to-door approach.*

Appendix X



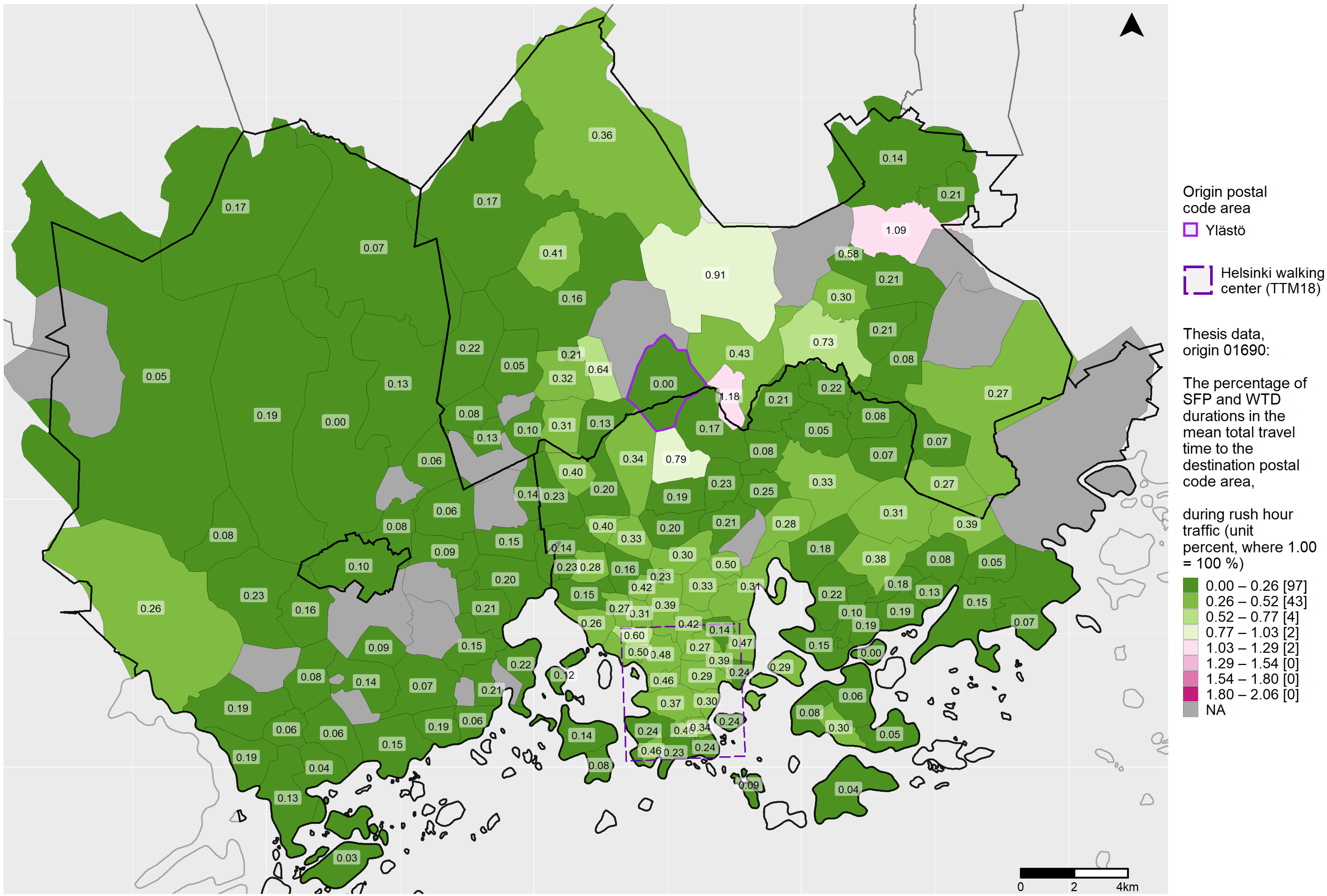
Appendix X. The parking process proportion in the total travel chain, in midday traffic, starting from 00430 Maununneva.

Appendix XI



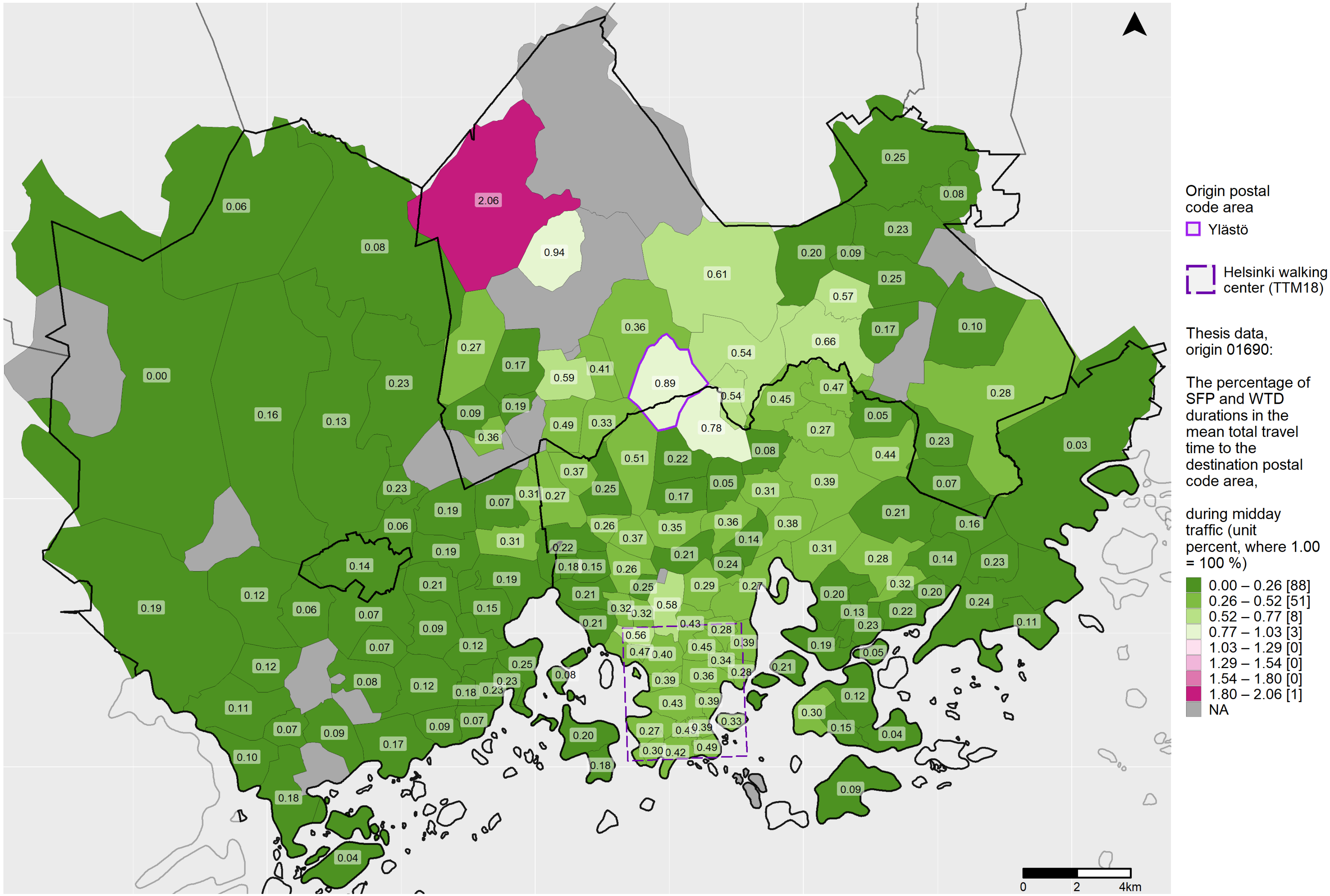
Appendix XI. The parking process proportion in the total travel chain, using all temporal values, starting from 00430 Maununneva.

Appendix XII



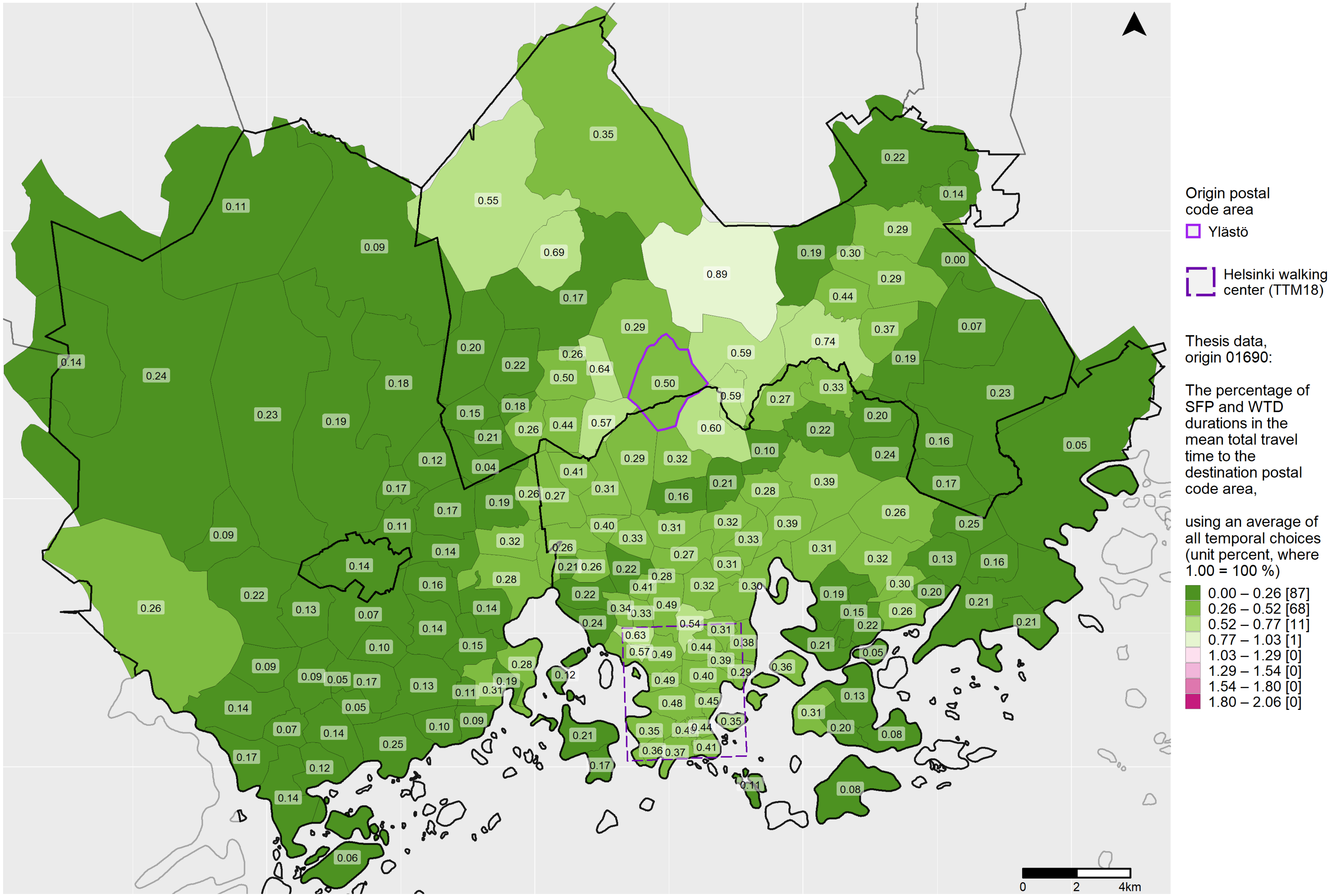
Appendix XII. The parking process proportion in the total travel chain, in rush hour traffic, starting from 01690 Ylästö. SFP stands for *searching for parking*, `parktime`, and WTD *walking to destination*, `walktime`. These are the components of the parking process in the *door-to-door approach.*

Appendix XIII



Appendix XIII. The parking process proportion in the total travel chain, in midday traffic, starting from 01690 Ylästö.

Appendix XIV



Appendix XIV. The parking process proportion in the total travel chain, using all temporal values, starting from 01690 Ylästö.